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NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

OTEC System Design Report

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Prepared for:
Naval Facilities Engineering Service Center (NAVFAC ESC)

Prepared by:
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The Navy views OTEC technology as a potentially viable means to reduce dependence on fossil fuel for electricity generation at bases located in tropical areas, including Naval Support Facility Diego Garcia (NSFDG), as well as naval facilities in Hawaii and Guam. The Navy's long term objective is the commercialization of OTEC technology to permit purchase of power and water from a privately developed OTEC facility at cost effective rates. Advancing OTEC technology to a commercially viable level is the subject of this design work.

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EXECUTIVE SUMMARY

Lockheed Martin supported by Makai Ocean Engineering, John Halkyard & Associates, Sound & Sea Technology, The Glosten Associates, G. Noland & Associates, Planning Solutions Inc, Navatek, OCEES, and E3Tek, completed a system design study for an OTEC Pilot Plant. The work was performed for the Naval Facilities Engineering Service Center, Port Hueneme under Contract N62583-09-C-0083, initiated 21 August 2009. This OTEC System Design Report provides the results of the design work.

The Navy views OTEC technology as a potentially viable means to reduce dependence on fossil fuel for electricity generation at bases located in tropical areas, including Naval Support Facility Diego Garcia (NSFDG), as well as naval facilities in Hawaii and Guam. The Navy's long term objective is the commercialization of OTEC technology to permit purchase of power and water from a privately developed OTEC facility at cost effective rates. Advancing OTEC technology to a commercially viable level is the subject of this design work.

A key step to OTEC commercialization is deployment of a Pilot Plant of sufficient size to validate environmental assessment models, system performance, and system cost estimates such that commercial financers will be encouraged to invest in commercial scale projects. Therefore, Pilot Plant requirements included 5 MW net capacity, a two year test phase, and eventual scale up to 10 MW.

This report provides the system design results organized using an architectural layout of key subsystems. Report sections address requirements, the platform, power generation, power delivery, integrated instrumentation and control, water production as a secondary product, environmental management, installation, and decommissioning.

The report is augmented by many appendices providing in-depth details of many of the subsystems.

Based on results from this study, building a 5 MW sized Pilot Plant is completely within the current state of technology. The system design information was also used to generate a detailed cost estimate for the Pilot Plant which can now be used to identify subsystems to focus cost reduction efforts. If sufficient funding were identified closely following this report, a pilot plant could be installed as early as 2014. A successful pilot plant can be closely followed by a commercial power plant of 100 megawatts.

The detailed cost estimate is considered sensitive information and is provided in an addendum associated with this report. A second addendum provides the details for a commercialization plan outlining the steps needed to proceed from this report through the pilot plant phase and on to the first commercial plant.

1. INTRODUCTION

1.1 Background

The Naval Facilities Command (NAVFAC) Ocean Thermal Energy Conversion (OTEC) Project is structured to advance commercialization and promote future development of OTEC technology for Navy applications. The Navy views OTEC technology as a potentially viable means to reduce dependence on fossil fuel at bases located in tropical areas, including Naval Support Facility Diego Garcia (NSFDG), as well as naval facilities in Hawaii and Guam.

Navy's *long term objective* is the commercialization of OTEC technology to permit purchase of power and water from a privately developed OTEC facility at cost effective rates. Advancing OTEC technology to a commercially viable level is expected to involve several significant interim steps. At present, both industry and the Government are working on development of various subsystems and testing to validate component designs. As an example, the Department of Energy (DOE) is currently funding cold water pipe development/testing; and NAVFAC is supporting Congressional funded heat exchanger development/testing and conducting additional efforts to assess OTEC feasibility and perform seafloor surveys at potential Navy OTEC locations.

The Navy's *near term objective* is to support technical efforts that reduce overall system developmental risks with respect to critical components and subsystems. The Navy awarded a contract in 2009 to a Lockheed Martin (LM) Industry Team to accomplish elements of the near term objective. Lockheed Martin supported by Makai Ocean Engineering, John Halkyard & Associates, Sound & Sea Technology, The Glosten Associates, G. Noland & Associates, Planning Solutions Inc, Navatek, OCEES, and E3Tek, has completed a system design study for an OTEC Pilot Plant. This effort is a key milestone leading to eventual OTEC commercialization, and ultimately the ability to purchase OTEC generated electricity from privately developed OTEC facilities. This work was performed for the Naval Facilities Command Engineering Support Center, Port Hueneme under contract N62583-09-C-0083 initiated on 21 August 2009. This report provides the results of the System Design task.

1.2 Document Scope

The general design approach of the LM Industry Team was to identify the Top Level Requirements for the OTEC Pilot Plant. Based on these requirements and on prior work accomplished under Internal Research and Design, engineering teams developed system and subsystem requirements and design concepts leading up to the ability to estimate the cost to fabrication the Pilot Plant. The focus of the design results are summarized in section 3. The layout of section 3 follows the system architecture presented in section 3.1 Appendices provide additional detail and insight into specific design details.

2. REFERENCE DOCUMENTS

The following documents are used to the extent specified herein.

2.1 Customer Documents

Document Title/Author	Date/Rev Status
Contract N62583-09-R-0083	24 June 2009

2.2 Program Documents

Document Title/Author	Date/Rev Status
Contract CDRL A001 Technology Development Plan	22 October 2009
Contract CDRL A002 Technology Development Report	21 September 2010
Contract CDRL A007 First Quarterly Status Briefing Materials Quarterly	3 December 2009
Contract CDRL A007 Second Quarterly Status Briefing Materials Quarterly	17 February 2010
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FLEXCOM	
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SOLIDWORKS Design software	
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American Bureau of Shipping (ABS) Guide for Building and Classing Floating Production Installations [Publication 0082]	Latest Edition (2009)
American Bureau of Shipping (ABS) Rules for Building and Classing Mobile Offshore Drilling Units (MODUs) [Publication 0006] – Part 3, Hull Construction and Equipment	Latest Edition (2008)
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Institute of Electrical and Electronic Engineers (IEEE) Standard 45 for Shipboard Cables	
International Maritime Organization (IMO) Lifeboats	

Specification or Standard and Source	Date/Rev Status
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3. SYSTEM DESIGN

The "System" as defined for this document consists of multiple related systems associated with the installation, startup/commissioning, sustained operations, environmental monitoring, and decommissioning/de-installation of the NAVFAC OTEC Pilot Plant. As shown in Figure 3-1, the four supporting systems to the operational OTEC Pilot Plant System include the Cold Water Pipe Fabrication System and the Installation System, the Environmental Management System, and the Decommissioning System. As part of this System Design Report, all will be covered with the exception of the Cold Water Pipe Fabrication System. Details of the design of that system are covered in the companion Technology Development Report delivered as Contract Data Requirements List (CDRL) A002 under this contract. The OTEC System Architecture details are shown in Figure 3-2.

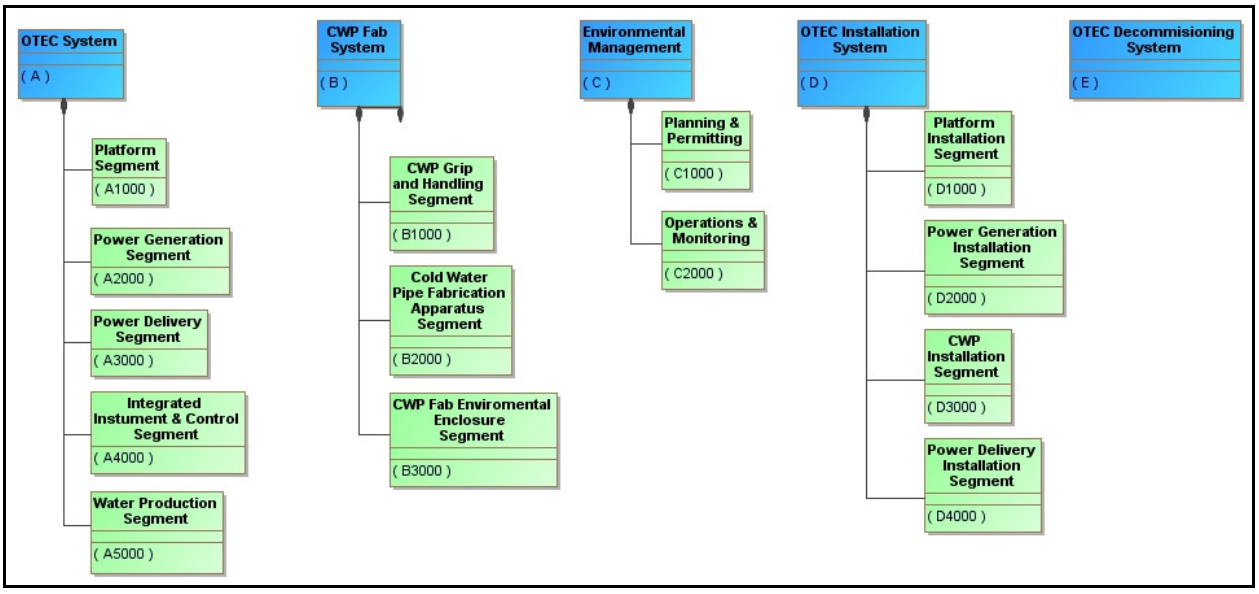


Figure 3-1. OTEC Pilot Plant Overall System Architecture Diagram

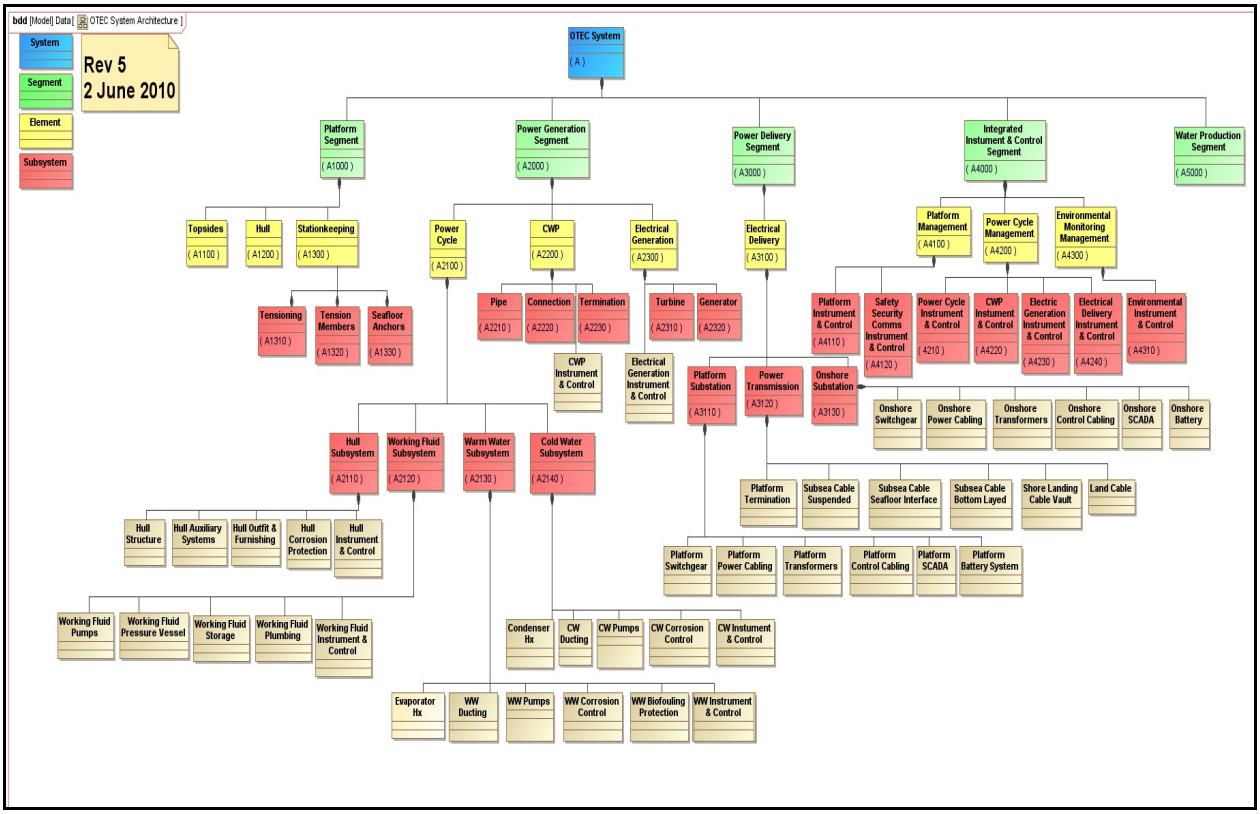


Figure 3-2. OTEC Pilot Plant System Architecture Diagram

Requirements analysis, Segment/Element/Subsystem/Component derived requirements and specifications, design drawings, trade studies, analysis results, and recommended "next steps" for maturing the preliminary designs completed under this contract are all detailed in this document. Consideration of specific installation site conditions and limitations are integral in the design presented. In addition, the cost estimates developed for the 5 Megawatt (MW) Pilot Plant include realistic estimates of any and all penalties associated with deployment and use of specialized support vessels for transportation of key system elements (e.g., platform) to and installation of key elements (e.g., anchors, submarine power cable) at the selected Hawaii location.

3.1 Integrated System Overview / Top Level Requirements (TLRs)

Top Level Requirements were developed at the start of the contract and represent the objectives of NAVFAC and the LM OTEC Team to develop an OTEC Pilot Plant of sufficient scale to address commercial scale up using one intermediate step. From discussions with the Hawaiian Electric Company (HECO), 5MW represents a scale with which they are comfortable for demonstration of a "first of its kind" type of independent power generator. From discussions with the National Oceanic and Atmospheric Administration (NOAA), and based upon early modeling of warm and cold water use and discharge, this scale of OTEC plant appears to be

large enough to observe some local effects and provide data for validation of models and observation of effects on the local marine environment.

3.1.1 Description

The set of Top Level Requirements agreed upon and base-lined for this contract are contained in Table 3-1 below.

Table 3-1. OTEC Pilot Plant Top level Requirements (Revision B Draft)

Top Level Requirements
Location: Southwest / west side of Oahu, HI
Capacity: 5 MW, annual net average electric power at grid interface during Pilot Plant phase
Grid Interface: Cabled to TBD Pearl Harbor site, interface in accordance with necessary Hawaiian Electric Company / NAVFAC renewable power requirements
Test Duration: Minimum 2-year pilot plant test phase
Configuration: Pilot Plant system and subsystems should scale up to commercial utility capacities ≥ 100 MW minimizing need for further risk reduction activities
Upgrades: Ability to upgrade to 10 MW annual net average electric power at grid interface
Design Life: Minimum 20 years beyond the pilot plant phase

3.1.2 System Concept of Operations (CONOPs)

The CONOPs associated with the NAVFAC OTEC Pilot Plant calls for a multi-year development, integration and installation phase for the 5MWe plant, followed by 2 years of Pilot Plant checkout and operations at a site just off of Pearl Harbor. A possible follow-on phase at either the original Pearl Harbor site or a to-be-determined alternative DoD Pacific site (the most likely candidates being either Pacific Missile Range Facility (PMRF) or Diego Garcia). This follow-on phase could possibly involve an upgrade to 10MWe or some combination of power output expansion plus potable water production, and would last for up to 20 years. Finally, following the operational period, a decommissioning/de-installation phase will be required. Some features of the concept presented herein and which support this CONOPs include:

- Distributed Fabrication
- Parallel Site preparation
- Near term start for collection of baseline data, with continued environmental monitoring during 2 year Pilot phase operations
- Integration near installation site (Honolulu, Pearl Harbor)
- Startup / checkout / commissioning
- Subsea power cable installation for connection to Pearl Harbor for power delivery

- Modular design supports efficient scheduling of upgrades
- Temporary moorings to minimize "sunk costs" at Site 1 in case of eventual Relocation

3.1.3 Assumptions

At the time certain design decisions had to be made under this contract, limited data existed on seafloor conditions for the selected installation site. Preliminary data from a first survey suggest that an adequate sediment layer exists in some spots for the use of drag embedment anchors. More data is needed to finalize this concept.

Hickam Air Force Base (joined with Pearl Harbor Naval Base) will provide facilities to install shore based equipment, such as the vault at the shoreline for landing the power cable, a route for running cable to a Back Substation, and space at the substation for installation of equipments.

3.1.4 System Architecture

A System Architecture hierarchy is a partitioning relationship where the system is separated into smaller more manageable entities. The system is described in relation to a set of interacting system elements, each of which can be implemented to fulfill its respective system requirements.

The first level of partitioning is "System." Systems are likely to be operational in their own right and can have different life cycles. Some of the system elements may be in their development life cycle while others are already deployed as operational. Definition and control of the scope of a system and managing the boundaries of the system elements are essential to the definition and management of the external interfaces.

The first step in System Architecture definition is the specification of functional and performance boundaries. External interfaces to interacting systems and humans external to the system were clearly defined, defining a system level boundary. A Systems Engineering Integration and Test (SEI&T) Integrated Product Team (IPT) task is to clearly identify system elements and organize IPTs with design control within the project team. In addition to Total Lifecycle Cost (TLC), design constraints including physical limitations (e.g. weight, form/fit factors), manpower, personnel, and other resource constraints on operation of the system, and defined interfaces with host platforms and interacting systems external to the system boundary are carefully considered and added to the requirements matrix.

The following systems were defined for OTEC;

- OTEC System – All aspects of the generation and delivery of power by the OTEC thermodynamic cycle
- Cold Water Pipe (CWP) Fabrication – Apparatus for fabrication of the cold water pipe, removed upon completion of fabrication and prior to OTEC operation
- Environmental Management – Not a system in the sense of being a physical entity, but contains all the top level direction for compliance with all Environmental Requirements, established as a system as environmental compliance is critical to the success of OTEC

- OTEC Installation – Any components necessary only for installation phase
- OTEC Decommissioning – Any components necessary only for decommissioning phase

The OTEC Systems and the next level below are shown below in Figure 3-3.

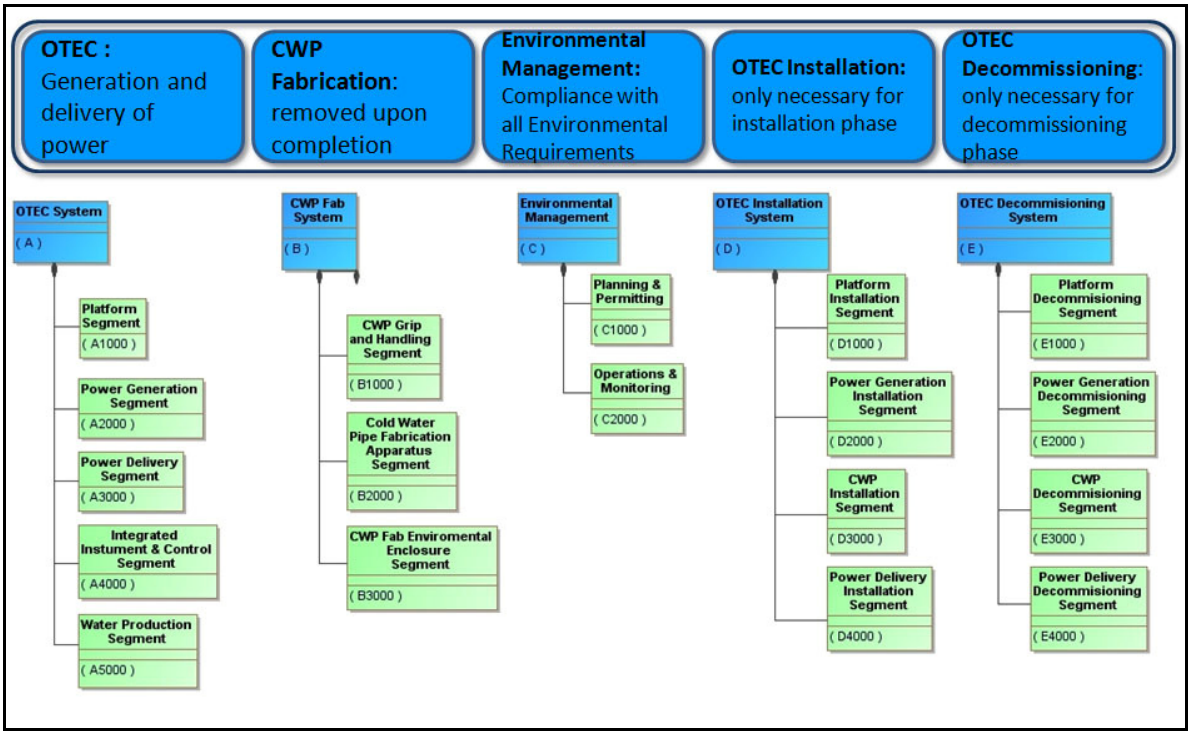


Figure 3-3. OTEC Architecture – System Definition

The next step is a hierarchical Specification Tree, shown in Figure 3-4 for the OTEC System covering the system and specifications for each configuration item of the system under development. This activity represents the establishment of the documented baseline of a particular level of the system design. These baselines are captured in configuration item specifications. The specifications document the set of configuration items for example, hardware, software, and operations, which will implement the system.

For this phase, an objective was to create a specification baseline for each of the configuration items and place these specifications in a flow down hierarchy. This allows further definition of each configuration item to proceed independently, in parallel with all the others, while maintaining requirements traceability and compatibility of all items that make up the system.

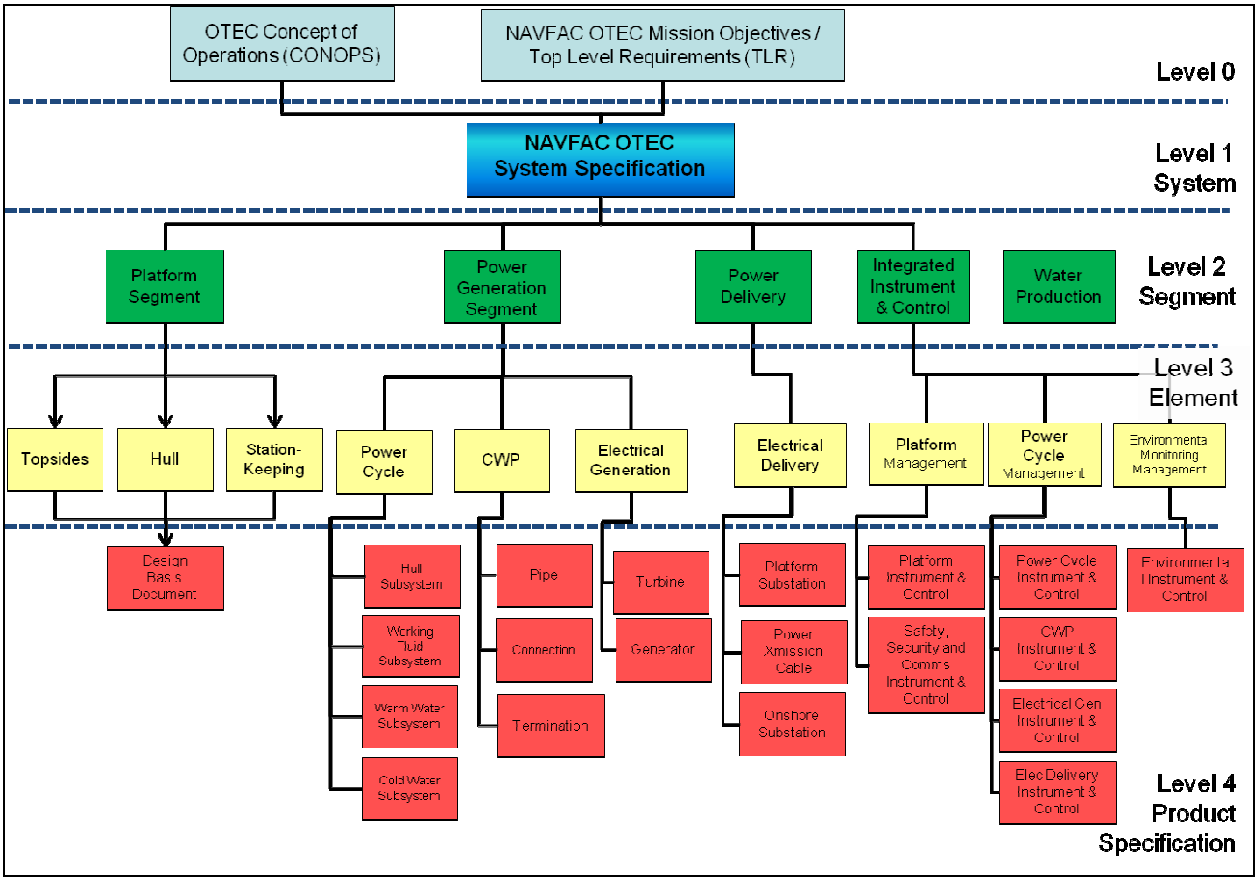


Figure 3-4. OTEC System Specification Tree

In order to automate the maintenance of the specification tree and requirements analysis process, a Microsoft Excel® workbook was designed to capture the system specification tree. A portion of one worksheet of the Excel workbook is shown in Figure 3-5. Portion of the Microsoft Excel Version of System Specification Tree. The portion captures the OTEC Systems and Segments shown on the left-hand side of Figure 3-3. OTEC Architecture – System Definition. In each of the system/segment/element boxes, a hyperlink has been inserted that takes the user up/down in the system structure. In context, the hyperlinks also jump to the requirements at the same level in a separate requirements workbook. The first pages of this workbook contain the top level requirements (TLR) and are discussed in detail in the next section of this document.

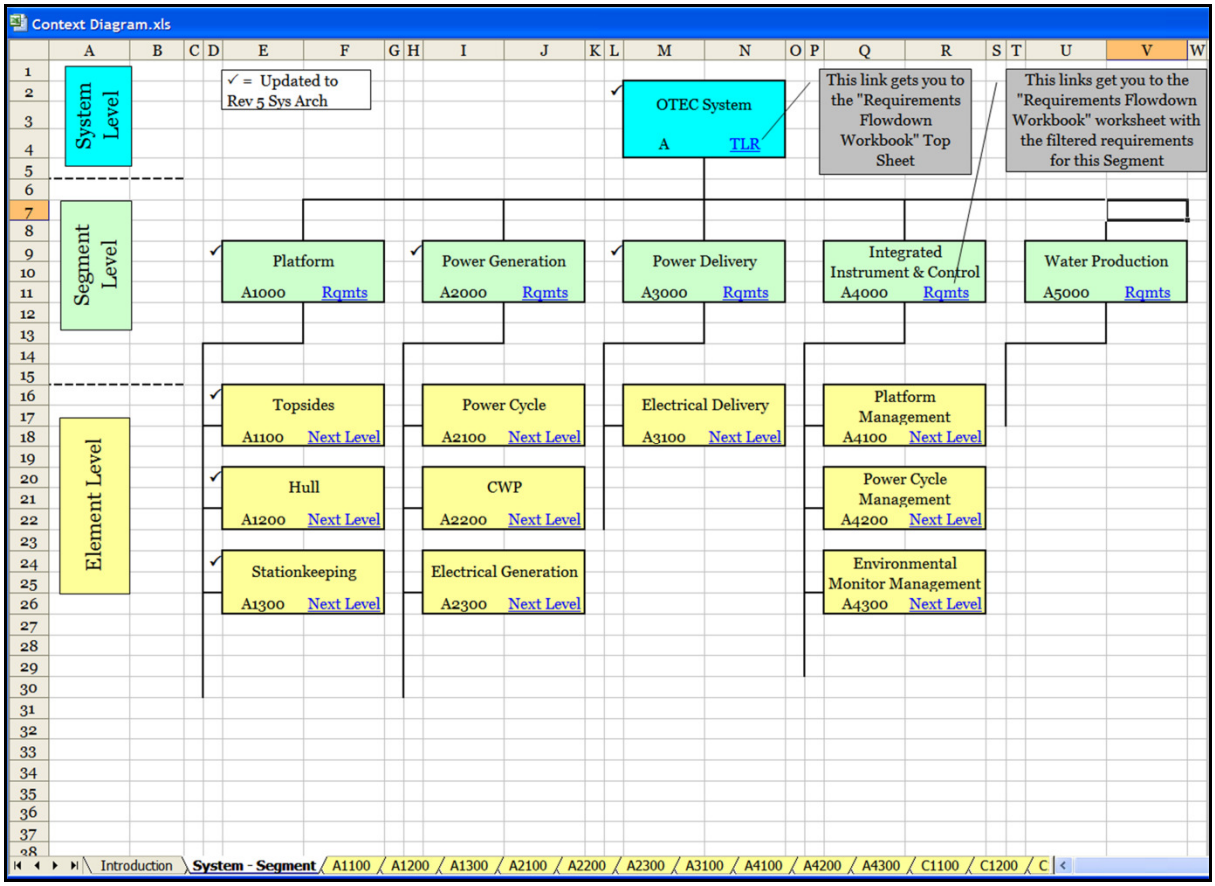


Figure 3-5. Portion of the Microsoft Excel Version of System Specification Tree

3.2 Pilot Plant Requirements

Once the TLRs and System Architecture had been defined, the next step is the Requirements Analysis Process. The purpose of the Requirements Analysis Process is to review, assess, prioritize, and balance all stakeholder and derived requirements (including constraints); and to transform those requirements into a functional and technical view of a system description capable of meeting the stakeholders' needs. Additional inputs included applicable statutes, regulations, and policies, applicable standards, environmental and safety concerns.

The output of Requirements Analysis is a technical description of characteristics the future system must have in order to meet Stakeholder Requirements – not a specific solution – which will be evolved in subsequent development processes. This baseline is captured in the OTEC System Level Requirements matrix in Appendix 3.2-1 and formed the primary input to the requirements flowdown (aka allocation) process described next.

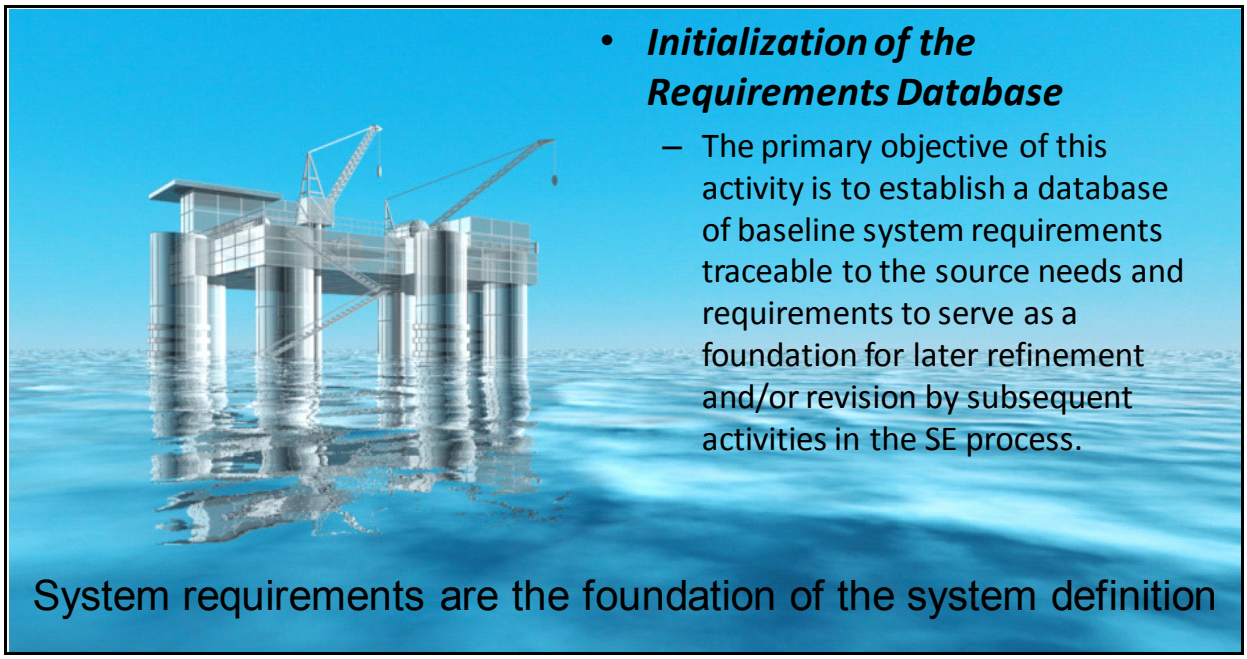


Figure 3-6. Requirements Database Initialization

The following is a brief outline of the requirements flowdown process used:

- Description of how and where requirements were gathered
- Description of how requirements were flowed down, organized and maintained
- Summary of requirements work completed

For the pilot phase of the project, system level requirements were gathered from the NAVFAC Contract Deliverables documents listed in Section 2.2 of this document. These TLRs were supplemented with derived requirements and constraints from subject matter experts (SME). The process continued throughout the Pilot Project phase.

An important part of the System Engineering (SE) process during the Pilot Phase is to flowdown, i.e. allocate requirements to lower levels of the system specification tree. For the Pilot Project phase, automation using the built-in features of Microsoft Excel®, such as hyperlinks and macros were used on the TLR matrix captured in a Microsoft Excel® Workbook. The resultant workbook features mechanisms to identify the origin, allocation and status of each requirement. A unique requirement identifier using nomenclature originated in the Systems Specification Tree allows bi-directional or "from – to" and "to – from" traceability.

Figure 3-7 depicts the requirements flow down process.

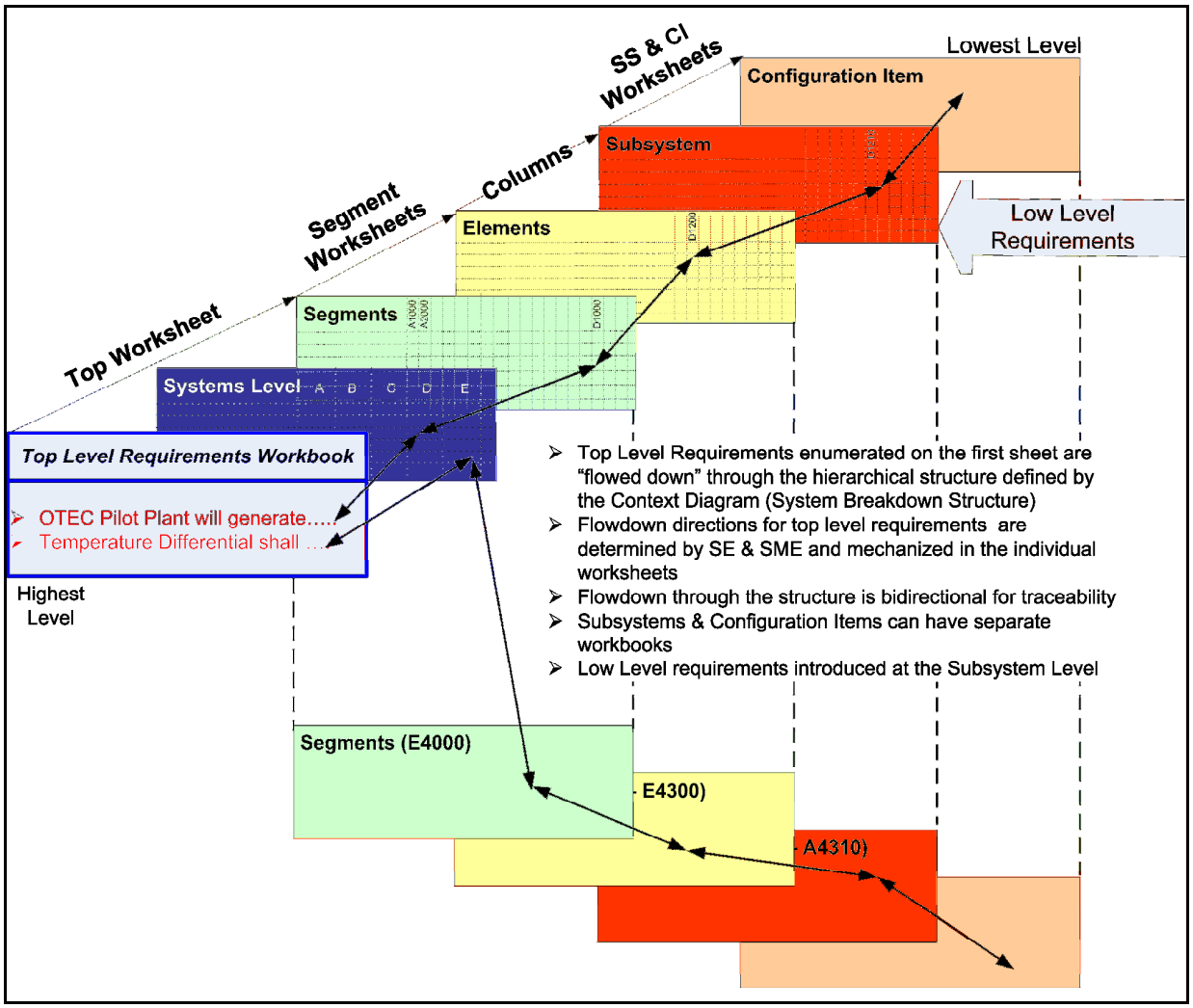


Figure 3-7. Requirements Flowdown Process

Tracing requirements bi-directionally through the systems architecture is a multi-dimensional problem. Spreadsheets are not generally suited for problems with more than 3 dimensions (2 dimension worksheet + multiple worksheets); however it can be done using multiple workbooks using hyperlinks without making the implementation seem too arcane.

The main feature in Figure 3-7 is the catalog (aka database) of TLRs on one worksheet of the "Top Level Requirements" workbook shown at the middle left of the figure. On the same worksheet, column headings for each of the five systems (A – E) are shown in the dark blue shaded block and column headings for the segments for each of the systems are shown in green shaded blocks. Flowdown detail at the segment level is captured on multiple worksheets in the workbook. On each Segment Level worksheet, flowdown detail to the Element (yellow shading) and Subsystem (red shading) levels are captured in columns. Again the information in the Subsystem columns is captured in separate workbooks. The reason for this is twofold: 1) the workbook cannot handle more dimensions easily and 2) to capture the derived requirements

introduced during the design process by SMEs. The lowest level in the structure is the Configuration Item; this document may cover a design, procurement or software specification.

The bi-directional, upper and lower chain of arrows is meant to illustrate how one TLR is traced through the architecture. Introduction of derived requirements at the Subsystem Level is for convenience and can be changed without impacting the process.

The best way to describe the method and tools used to track requirements is through an example. In Figure 3-8 a top level requirement is traced through the flown down process. As previously discussed, Microsoft Excel® Workbooks (one or more worksheets) were used to mechanize the process. In the figure, the sample TLR has several attributes: a unique number, origin, vetted, requirement (rqmt), to be determined (TBD), segment and system specifier fields. In turn, these attributes allow the user to identify, trace, status and allocate the requirement. The latter two "specifier" fields are used by Excel logic functions to allocate or flowdown the requirements to one or more systems and segments. For example, the system specifier "OTEC" directs the requirement to one of the five systems shown in the "Systems" table in the figure denoted with a double X. The segment specifier "All" results in double X's in all segments of that table in the figure. The double X's are placed automatically by Excel functions. The lowest requirement flowdown level for the Pilot Phase was chosen to be the Subsystem Level. That step from "Segment" through "Element" to "Subsystem" is shown in the table at the bottom of the figure. Each of these levels are shown as columns in the table. Each of the column headings are hyperlinked allowing easy navigation through the worksheets.

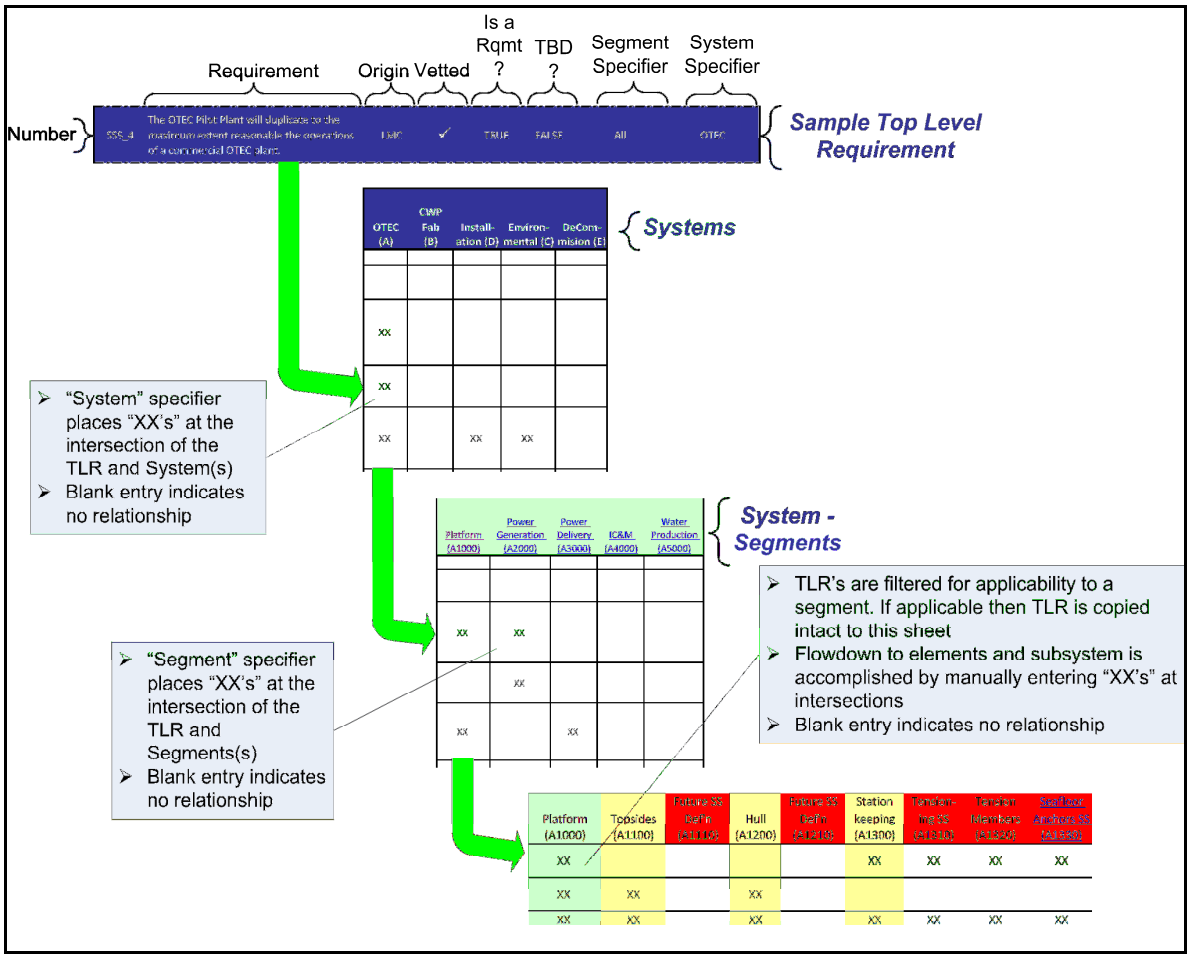


Figure 3-8. Example Requirement Flowdown

The work accomplished during the Pilot Phase to identify, organize, allocate and maintain requirements provides a solid foundation for the future as refinements and revisions are made to an ever increasing matrix of requirements.

3.3 OTEC Pilot Plant System

There are five Segments in the OTEC System:

(1) Platform

(2) Power Generation

(3) Power Delivery

(4) Integrated Instrumentation and Control

(5) Water Production

Each Segment consists of one or more Elements, Subsystems and Components. The Segments are described in detail in the following sections.

(1) Platform Segment

The platform's function is to house the OTEC plant. It consists of the Topside, Hull and Stationkeeping Elements as shown in Figure 3-9 and Figure 3-10.

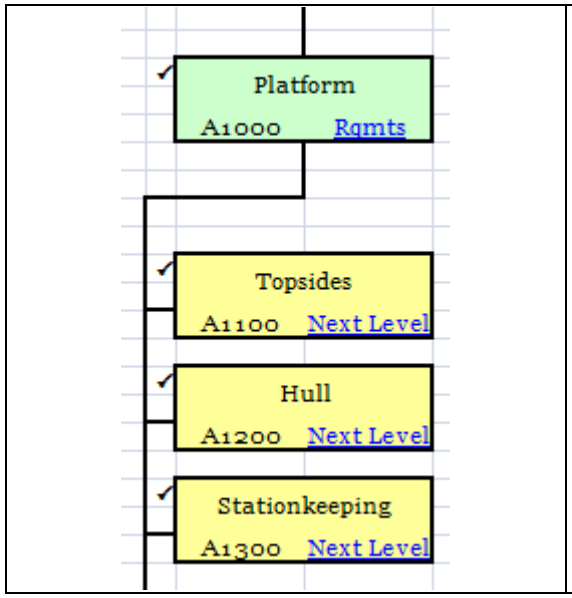


Figure 3-9. Platform Segment Contents

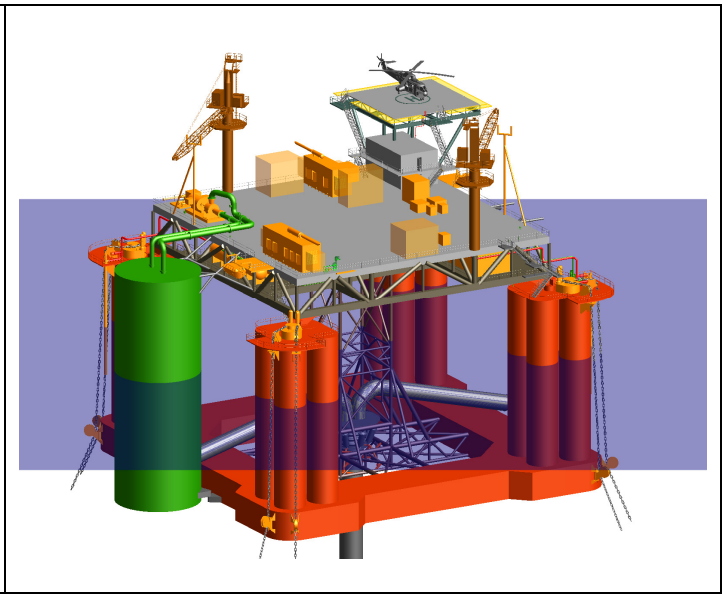


Figure 3-10. Platform Segment Concept

(2) Power Generation Segment

The purpose of the Power Generation Segment is the generation of the power. It consists of the Power Cycle, CWP and Electrical Generation Elements as shown in Figure 3-11 and Figure 3-12.

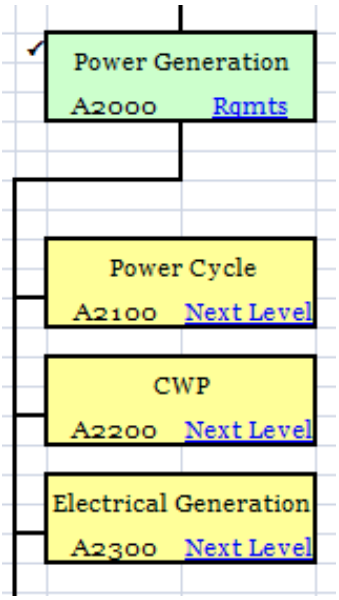


Figure 3-11. Power Generation Segment

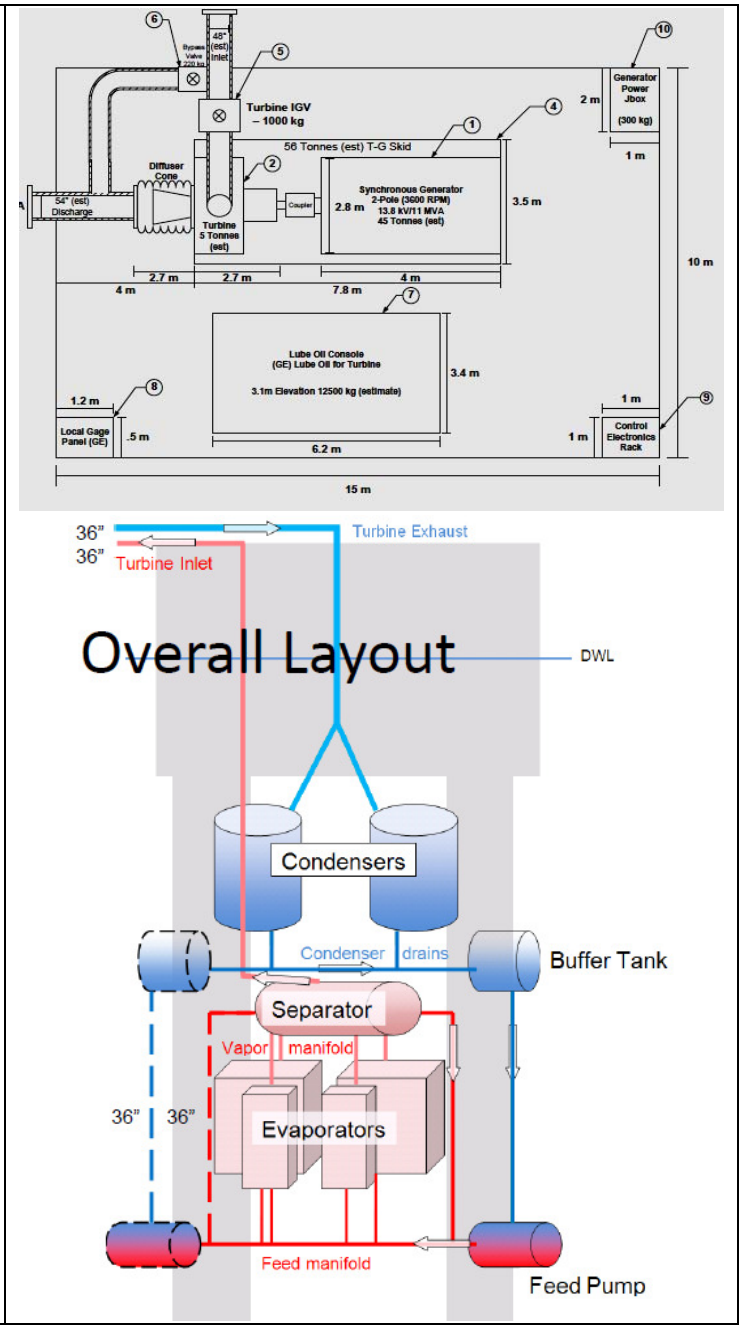


Figure 3-12. Power Generation Concept

(3) Power Delivery Segment

The purpose of the Power Delivery Segment is to transport the power from the Power Generation Segment to the onshore substation as shown in Figure 3-13 and Figure 3-14.

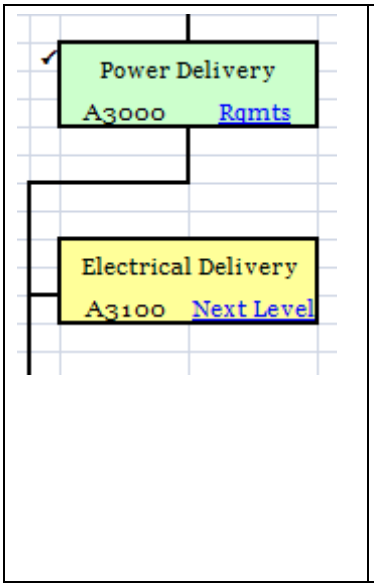


Figure 3-13. Power Delivery Contents

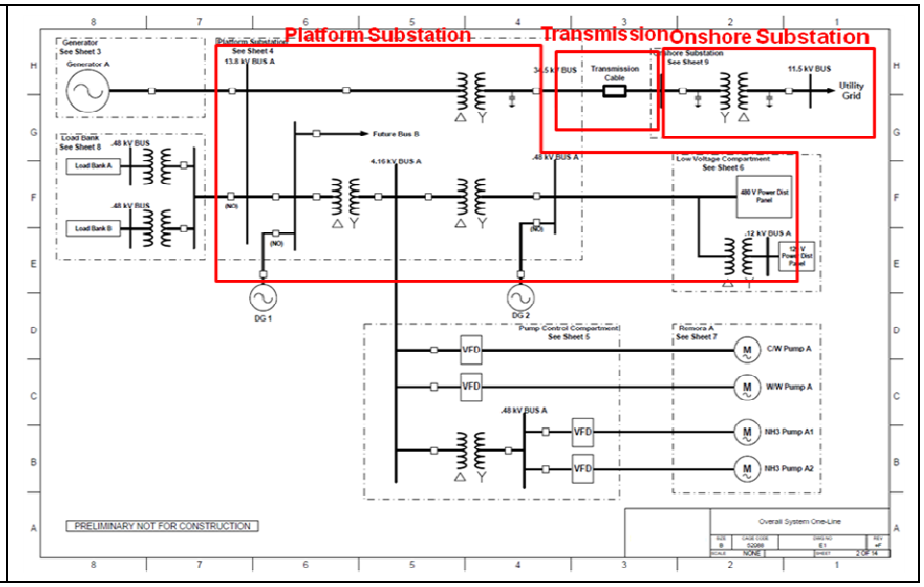


Figure 3-14. Power Delivery Concept

(4) Integrated Instrumentation and Control Segment (II&C)

The purpose of the Integrated Instrumentation and Control Segment is to provide monitoring and control of all functions on the other segments. It consists of Platform Management, Power Cycle Management and Environmental Monitoring Management Elements as shown in Figure 3-15 and Figure 3-16.

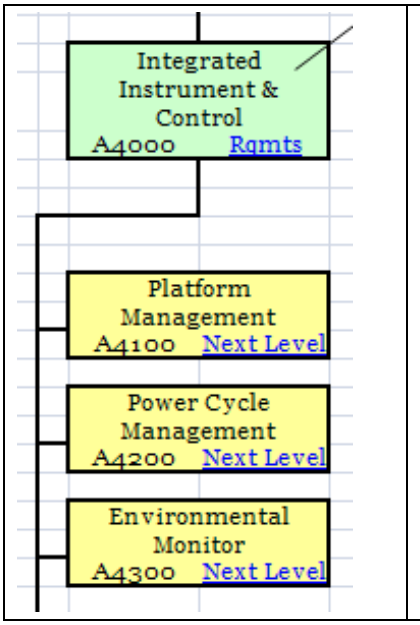


Figure 3-15. Integrated Instrument and Control

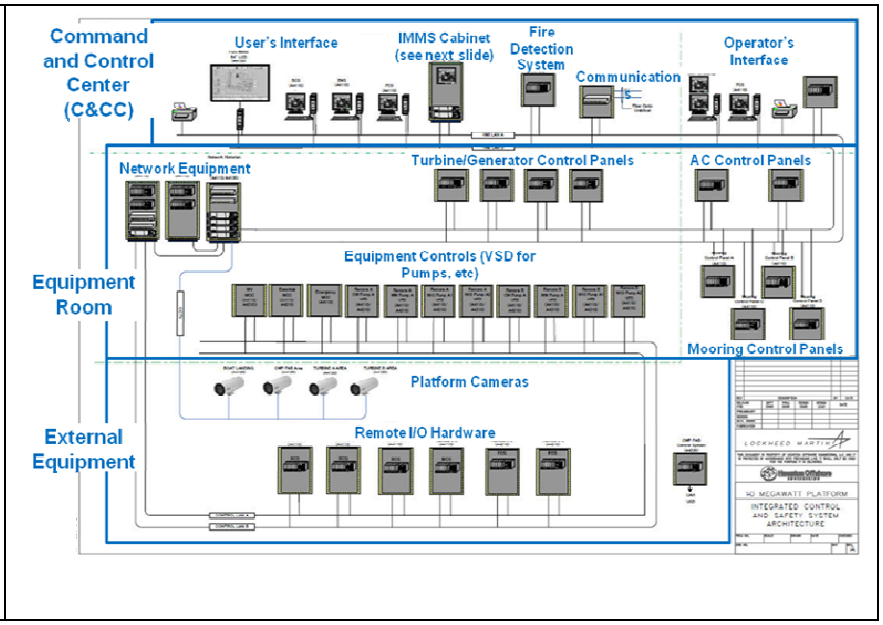


Figure 3-16. Integrated Instrument and Control Concept

(5) Water Production Segment

The Water production Segment is an optional segment that provides potable water as a byproduct of the system operation as shown in Figure 3-17.

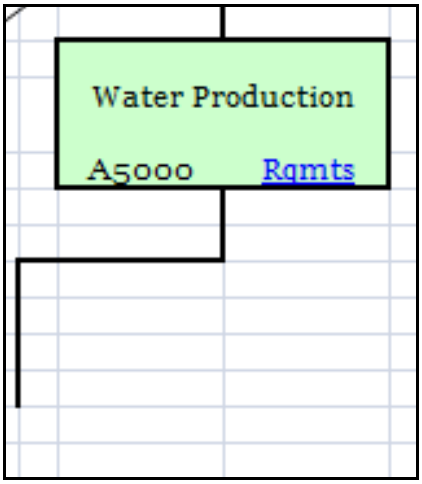


Figure 3-17. Water Production Contents

3.3.1 Platform Segment (A1000)

3.3.1.1 Functions and Interfaces

The platform segment consists of three elements:

(1) Topsides including platform deck, equipment, accommodations, piping and electrical hookups.

(2) Hull providing buoyancy to support the deck, and

(3) Stationkeeping to maintain the platform on location.

The platform supports virtually all of the OTEC functions and thus there is a key interface to most of the other systems as shown in Figure 3-18.

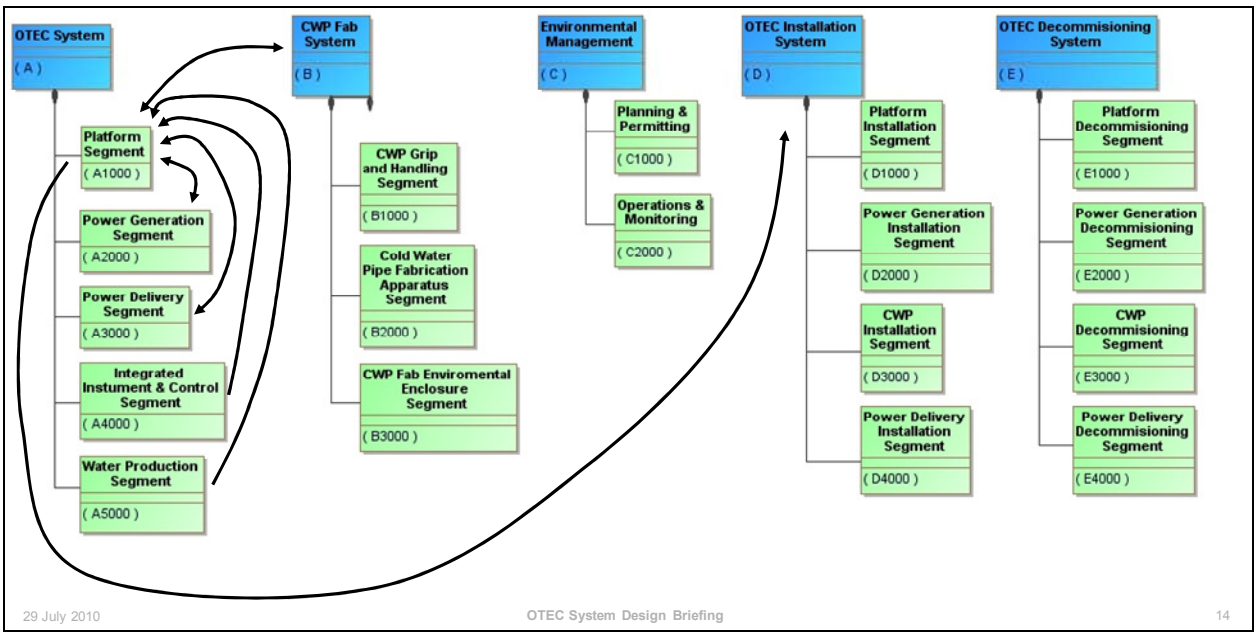


Figure 3-18. Platform Segment Interfaces

The key driving requirements for the platform are summarized in Table 3-2. The primary and most basic requirement of the platform is to "stably support the OTEC payload above the highest waves." This is fundamental to all floating platforms but must be emphasized. This drives the basic sizing: providing sufficient deck area, buoyancy and stability while maintaining the deck high enough to be unaffected by the highest waves. Another primary requirement of the current OTEC design is to minimize the motions due to waves. This is derived from the proposed method of pipe fabrication and installation. This issue is discussed at length in the companion Technology Development Report[i]. This requirement led to the current semi-submersible platform selection. Another driving requirement of the OTEC system is to extract water in large volumes from 1000 m depth. This leads to the need for a deep water mooring system. Supporting a power cable to shore imposes another requirement on the mooring system, that it maintain a watch

circle of less than about 100 m to prevent damage to the cable. The power cable also demands that the motions of the platform meet certain minimal standards, but these are not as onerous as the requirements of the large diameter cold water pipe during fabrication. The final requirement is that, after the pilot test phase, the platform must be capable of reliably producing power over an extended period of time for commercial operations. A nominal period of 20-years has been selected for this requirement; however it is likely that there would be a desire to extend this life if possible[1].

Table 3-2. Platform Key Design Requirements

Requirement	Source	Rationale	Impact
To stably support the OTEC payload above the highest waves	Fundamental	Requirement of floating systems.	Basic platform sizing must meet minimum deck area, stability, and air gap requirements.
Support Pipe Fabrication Activity	Top Level Requirement	Simulate and demonstrate prototype selected method of pipe manufacturing.	Additional deck space required. Platform motions must be limited during fabrication.
Support OTEC Power System with Cold Water Pipe to 1000 m depth.	Top Level Requirement	Large diameter pipe cannot be economically installed to 1000 m depth from shore.	Stationkeeping system must maintain platform over 1000 m+ water depth. Motions must be acceptable to support cold water pipe.
Support power cable to shore.	Top Level Requirement	Demonstrate power delivery and grid connection.	Stationkeeping system must restrict watch circle to about 10% of water depth.
Support power generation for up to 22 years	Top Level Requirement	Provide renewable energy for US Military needs.	Service and fatigue life requirements.

3.3.1.2 Design Criteria

There are three distinct phases to the operation of the platform:

Stage 1 – Pipe Fabrication

Stage 2 – Pilot Plant Testing

Stage 3 – Commercial Operations

1 Offshore platforms are typically designed for 20 – 20 year life. This is to some extent driven by the assumed life of the oil reservoir. OTEC does not have a reservoir life so there is no reason not to consider design lives for OTEC platforms of 30 – 40 or more years. Many offshore platforms have actually been in operation over 50 years with suitable renewal work and recertification.

The primary design criteria related to length of service and design environment for the three stages are listed in Table 3-3.

Design criteria may be broadly organized as:

- Payload – The weight and area requirements of the processes to be supported
- Rules and Standards – What industry standards are to be applied to the design. This includes environmental standards.
- Met-Ocean Conditions – What are the sea states (wind, waves and currents) that the platform must operate in? What are the mid-water temperatures and other properties?
- Bathymetric and Geotechnical Conditions – What are the water depths and the seabed conditions for anchoring?

Table 3-3. Platform Design Criteria

		Time	Exposure
All Stages, Platform Structure, Cold Water Pipe, Cable to shore. Design to ABS Class Requirements		22 years	100-yr Event
Stage 1: CWP Fabrication	Fabrication Tower and CWP load	Short time exposure , Fab System removed after pipe installation	- 90% sea /swell for CWP fabrication - 10-yr sea/swell for standby survival
Stage 2: Pilot Plant Operations	1 Power System unit (5MW) operational, Cable to shore	2-yr exposure	Temporary mooring: 25-year cyclone
Stage 3: 10MW Production	2 Power System units	20-yr exposure	Permanent Mooring: 100-year cyclone

3.3.1.2.1 Payload

The payload for the platform includes:

- OTEC Power generation equipment, instrumentation, etc.
- Secondary steel weight for supporting the equipment (e.g. module weight)
- Utilities module weights (accommodations, helideck, etc.)
- Piping and electrical bulk weights
- Primary Deck steel for supporting the above
- Vertical loads from cold water pipe, power cable and moorings

Payload is the most critical driver for any floating platform because the amount of buoyancy must be adequate to support the payload. Excessive buoyancy is usually considered an expensive luxury. Detailed weights are reported in the following sections and Appendices 3.3.1-2 (Equipment) and 3.3.1-3 (Weight Management Report).

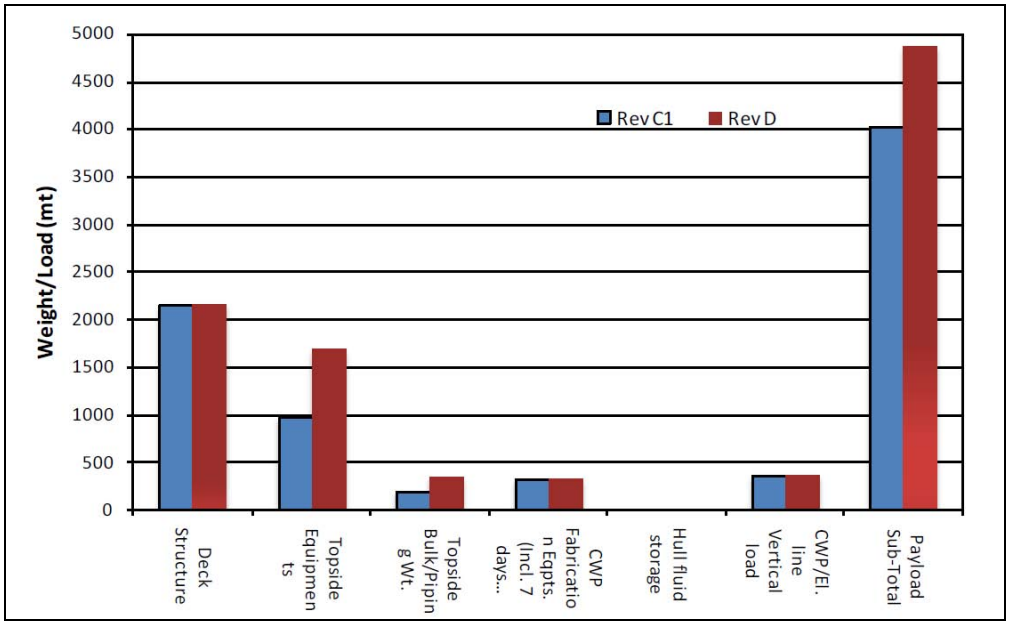


Figure 3-19. Stage 3 Payload Tracking (from Appendix 3.3-3)

Figure 3-19 shows an example from Appendix 3.3-3 of the payload for the full production case (Stage 3). This shows how the "final" payload changed from an earlier estimate as estimates of equipment weights were refined. This is why offshore projects are typically phased so that a large amount of engineering is performed on the process systems and topsides before the hull is selected. It can be very costly if the payload weights change after the hull has been designed!

3.3.1.2.2 Rules and Standards

There are no established design rules or standards for floating OTEC systems. We have adopted rules applicable to floating offshore platforms which are listed below. The owner of the platform may decide whether the platform and its components should be either certified or classified as meeting the American Bureau of Shipping (ABS) Rules once the project is sanctioned. "Certifying" a platform is a one-time assessment by the certifying agency that the platform has been designed and built according to the Rules. "Classing" a platform includes certification as well as continual inspection and determination that the in-service platform still meets the rules. Neither certification nor classification is required by regulation for an OTEC platform, but there could be provisions in the yet to be developed NOAA regulations that might require some form of certification, as is written into the Minerals Management Service (MMS) regulations for offshore oil platforms. Hence we believe it is prudent to use these Rules as a basis for the design at this stage. "Recommended Practices" (RP) as included in this list are industry recommended practices and are not subject to "certification" by ABS, however they are included indirectly as ABS will refer the American Petroleum Institute (API) RPs on occasion.

- American Bureau of Shipping (ABS), "Guidance Notes On Review And Approval Of Novel Concepts" June 2003
- American Bureau of Shipping (ABS) , "Guide for Building and Classing Floating Production Installations", latest edition
- American Bureau of Shipping (ABS), "Rules For Building And Classing Mobile Offshore Drilling Units - Part 3, Hull Construction And Equipment", latest edition
- ABS Rules for Conditions of Classification – Offshore Units and Structures, 2008
- American Bureau of Shipping (ABS) , "Guide for Building and Classing Facilities on Offshore Installations", latest edition
- American Petroleum Institute (2005), API RP 2SK Design and Analysis of Stationkeeping Systems for Floating Structures, Third Edition **or** DNV OS E301 "Position Mooring" Oct. 2008 (using Class 1 criteria)2
- American Petroleum Institute (2001), API RP 2SM, Recommended Practice for Design, Manufacturing, and Maintenance of Synthetic Fiber Ropes for Offshore Mooring, First Edition
- American Petroleum Institute, API RP2RD, Design of Risers for Floating Productions Systems and Tension Leg Platforms, Latest Edition
- American Petroleum Institute (2000), API RP 2A-WSD (21st Edition) "Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms - Working Stress Design" [Foundations, Wind Spectrum]
- American Petroleum Institute (2004), API BULL 2U, "Bulletin on Stability Design of Cylindrical Shells"
- DET NORSKE VERITAS (2002), DNV-RP-C202, "Buckling Strength of Shells"
- United States Coast Guard (USCG) Navigation Regulations, Subchapter N, Outer Continental Shelf Activities (33 CFR 140 et seq)

3.3.1.2.3 Metocean Conditions

Waves, wind and current affect the operability and survival of the platform and the OTEC equipment. The Cold Water Pipe is particularly sensitive to the environment, see [i]. The wind and wave conditions at the potential Hawaiian OTEC sites were the subject of hindcast studies conducted by Oceanweather, Inc[ii]. These studies included both operational seas and cyclonic storms at the potential Hawaiian sites. Except for the tropical cyclones, ocean currents are assumed independent of the waves and wind (wind driven currents are assumed to dominate for the cyclonic events). The only measured current data in the area comes from measurements taken

[2] DNV Consequence Class 1 applies when failure of a mooring system in not likely to cause unacceptable consequences such as loss of life, environmental disasters, etc. It is assumed that the consequences of a line failure to OTEC would at worst be parting of the power cable, and that a criterion should be set herein that the cable should be designed to allow for failure of one line in an environment less than the 100-year event. This should result in less overdesign of the mooring system.

with a tethered current array from June 1980 to June 1981[iii]. Figure 3-20 shows the statistical current profiles derived from the [iii].

The hindcast and current data discussed above formed the basis for deriving design met-ocean environments in Table 3-4.

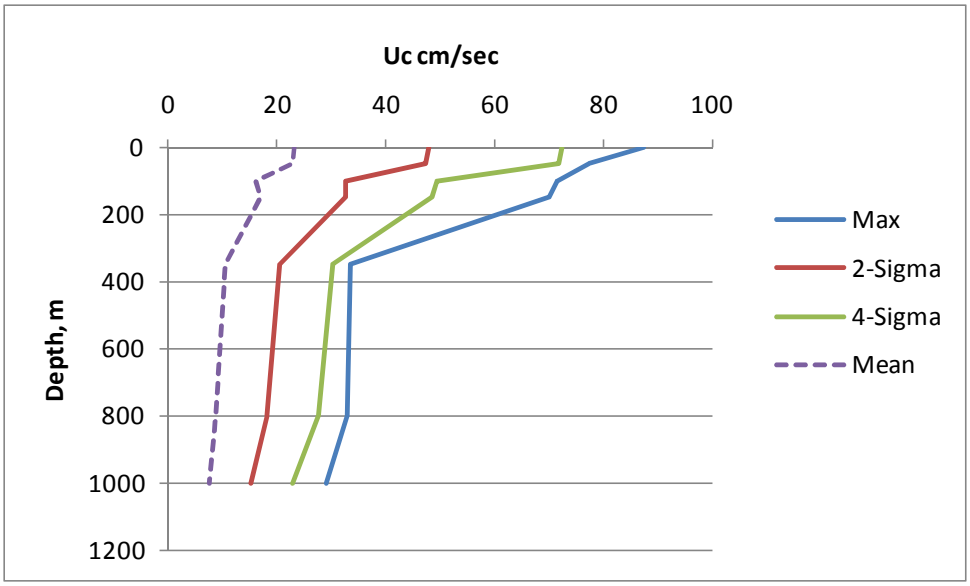


Figure 3-20. Current Profiles

The metocean conditions applicable to different stages are indicated in this table.

- Pipe installation shall operate under the 90% condition on an annual average.
- The CWP during installation shall survive a 10-yr event with operations on standby.
- The Pilot Plant shall survive an extreme condition corresponding to a 25-yr return period event.
- The commercial system shall survive at 100-yr return period event3.
- All stages shall survive the maximum current condition.

Fatigue environments have been derived from 25 years of operational hindcast data [ii]. The data has been parsed in 16 “bins” shown in Table 3-5.

[3] As of this writing no condition has been placed on operability of the pilot or commercial operations, however weather downtime during operations has been assumed inconsequential, less than 1-2%.

Table 3-4. Platform Met-Ocean Design Criteria

Criteria Used for:	100 Year Cyclone	25 Year Cyclone	25 Year Non-Cyclone (sea)	25 Year Non-Cyclone (swell)	Max Current	10-yr Sea (Barbers Hindcast) 2 sigma current	10 -yr Swell (Barbers Hindcast) 2 sigma current	90% Sea (Kahe) 4 sigma current	90% Swell (Kahe) 4 sigma current
Pipe Installation								X	X
CWP Fab Standby Survival					X	X	X		
Production Extreme	X				X				
Pilot Extreme		X	X	X	X				
Hs, m	10.2	4.3	4.5	4.5	1.5	4.2	3.8	2.0	1.5
Tp, sec	12.8	10.6	8.8	14.1	14	8.3	15.7	5.3	14
Spectrum, Jonswap gamma	2	2	1	6	6	1	6	1	6
U_{wind}, m/sec (10-min ave)	33.8	13.7	16.2	16.2	8	15.7	14.6	7.5	8
Uc, m/sec @ surface	1.4	.5	.6	.6	.9	.5	.5	.7	.7
Uc, m/sec @ 50m	.5	.5	.5	.5	.8	.5	.5	.7	.7
Uc, m/sec @ 100 m	.3	.3	.3	.3	.7	.3	.3	.5	.5
Uc, m/sec @ 150 m	.3	.3	.3	.3	.7	.3	.3	.5	.5
Uc, m/sec @ 350 m	.2	.2	.2	.2	.3	.2	.2	.3	.3
Uc, m/sec @ 800 m	.2	.2	.2	.2	.3	.2	.2	.3	.3
Uc, m/sec @ 1000 m	.2	.2	.2	.2	.3	.2	.2	.2	.2

NOTE: Hs – Significant Wave Height, Tp - Peak Wave Period

Table 3-5. Fatigue Bins (Barber's Point)

Bin	Freq of Occurrence	Hs m	Tp sec
1	0.00005	0.875	4.500
2	0.00545	1.125	5.340
3	0.07827	1.607	6.048
4	0.01173	2.179	6.490
5	0.00366	0.875	9.399
6	0.04110	1.125	9.988
7	0.16883	1.495	10.670
8	0.03050	2.478	8.853
9	0.00285	0.875	13.595
10	0.02866	1.125	13.571
11	0.25834	1.631	13.603
12	0.08433	2.297	14.010
13	0.00496	0.874	17.405
14	0.03106	1.125	17.554
15	0.18350	1.598	17.331
16	0.06664	2.397	16.943
Total	0.99993		

3.3.1.2.4 Bathymetric and Geotechnical Conditions

The selected site for the pilot plant is shown in Figure 3-21 along with the proposed cable route[iv].

Parameters for this site are:

- Coordinates: Lat: 21 deg 10' 8.9" N Long: 158 deg 7' 21.36" W
- Water depth: 1100 m



Figure 3-21. Bathymetry at the Selected OTEC Site [iv]

The site lies on a submarine slope of the southwestern corner of the island of Oahu, near Barber's Point. The site is on the edge of a 20 – 30 degree slope. Shoreward the slopes are much smaller, on the order of 2 – 3 degrees.

The available geotechnical data is insufficient upon which to base an anchor design using accepted procedures and techniques. As of this writing, there has been no core drilling or seafloor Cone Penetration Testing (CPT) at any of the proposed OTEC sites in Hawaii. All data to date is based on a small sample for shallow gravity cores, and anchor design has had to assume extrapolated soil strength profiles.

During earlier interest in OTEC, the US Geological Survey (USGS) performed a preliminary survey of the area off of Kahe Point in 1982[v]. These results were used in Lockheed's earlier anchoring studies [vi]. The USGS attempted to gather eight (8) seabed samples using gravity coring techniques [v]. Four (4) core samples were successfully recovered with core lengths from 1.75 to 5.5 m. The cores have been comprehensively described and tested by the USGS. The material recovered is described as calcareous ooze. The reason for this description is the very high carbonate content of the soil (between 69.5 to 86.9%) which suggests most of the material is of organic origin. In terms of grain size distribution the results indicate predominantly sand and silt, with some clay. Tests of undrained shear strength were performed on selected cores using shear vane equipment. The results reported suggest material classification is in the "very soft" i.e. undrained shear strengths of 20kPa or less. Values around 10kPa appear to be typical of the measurements recorded.

The USGS data was gathered 10 - 15 miles north of the currently proposed site. Earlier this year the Navy conducted a site survey of the proposed Barber's Point Site. Only preliminary results of this survey are available, however the data has been used in evaluating anchor alternatives described later in this report [vii]. The data appears to be consistent with the USGS data.

During the 2010 survey nine gravity core drops were attempted. Three full and three partial cores were recovered, three cores failed to recover any sediment, Figure 3-22. A contour plot of sediment thicknesses based on sub-bottom profiler results, Figure 3-23, indicates a possible reason for failure of core samples. Much of the area sampled has sediment thicknesses less than 1 m.

The shear strength results of the cores recovered in the 2010 cruise are shown in Figure 3-24. These are largely consistent with the USGS results discussed above. Based on this figure, the deepest core recovery in the Barber's Point cruise is about eight ft.

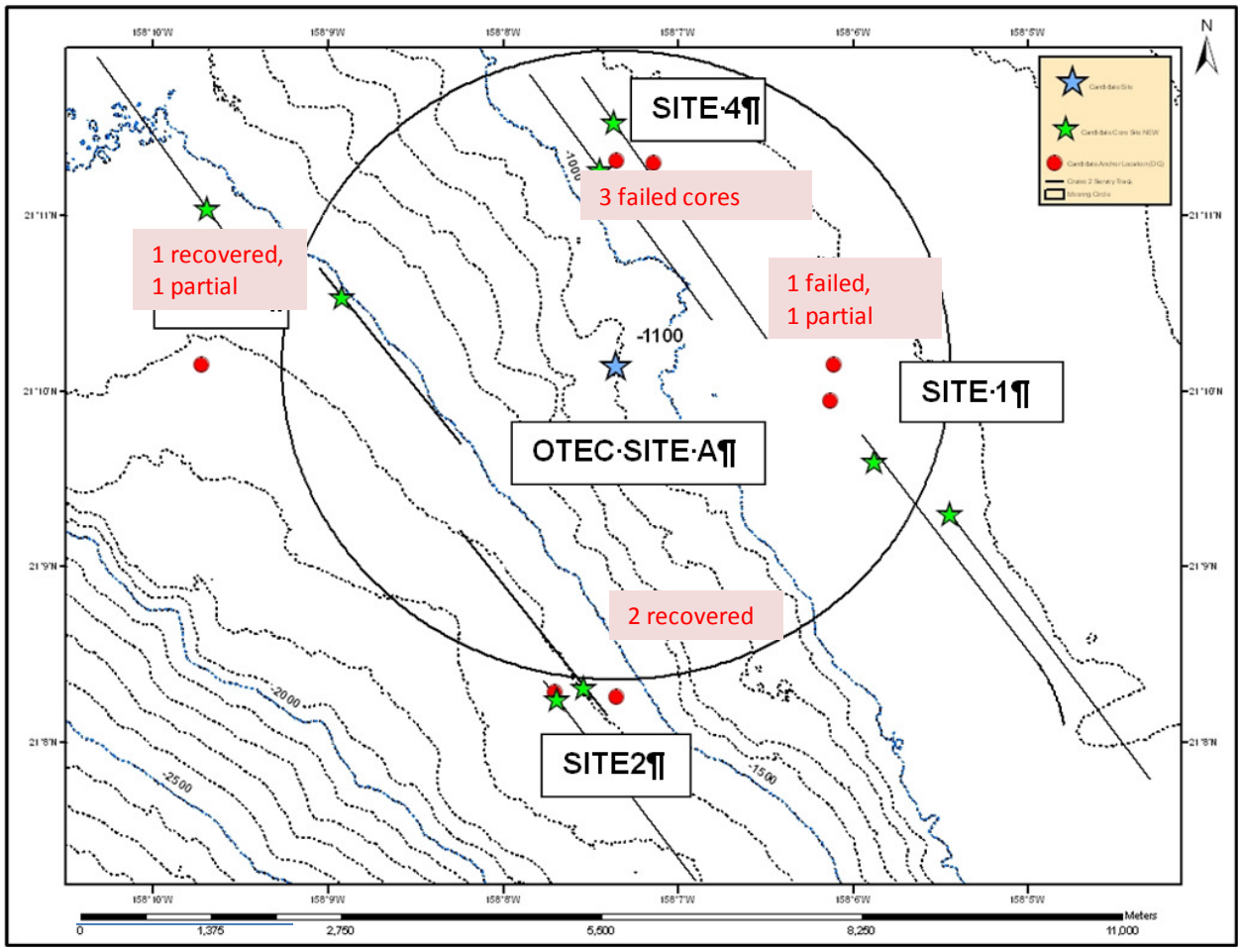


Figure 3-22. Anchor and Core Sample Locations, Barbers Point OTEC Site [viii]

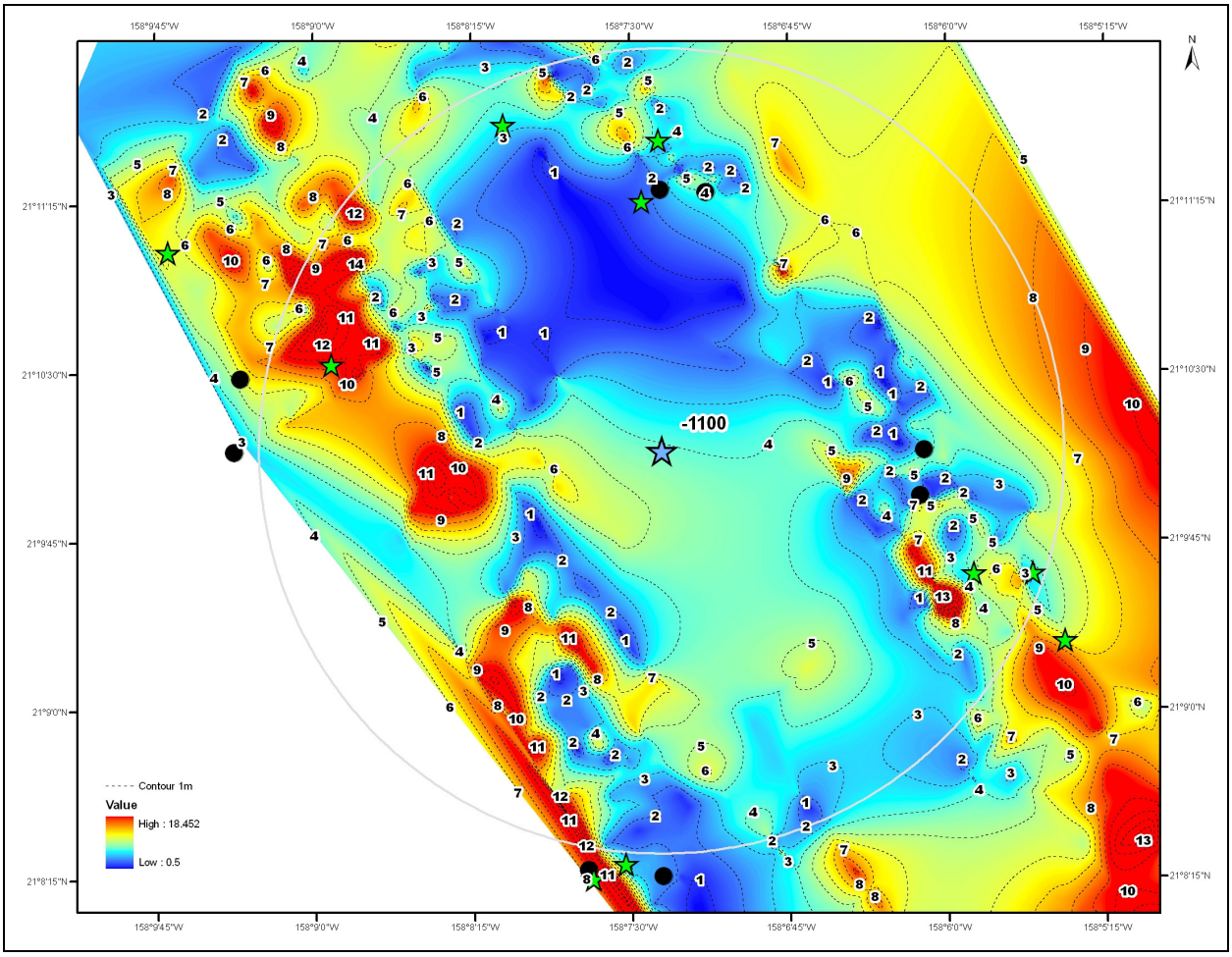


Figure 3-23. Preliminary Isopach (Sediment Thickness) Contours[ix]

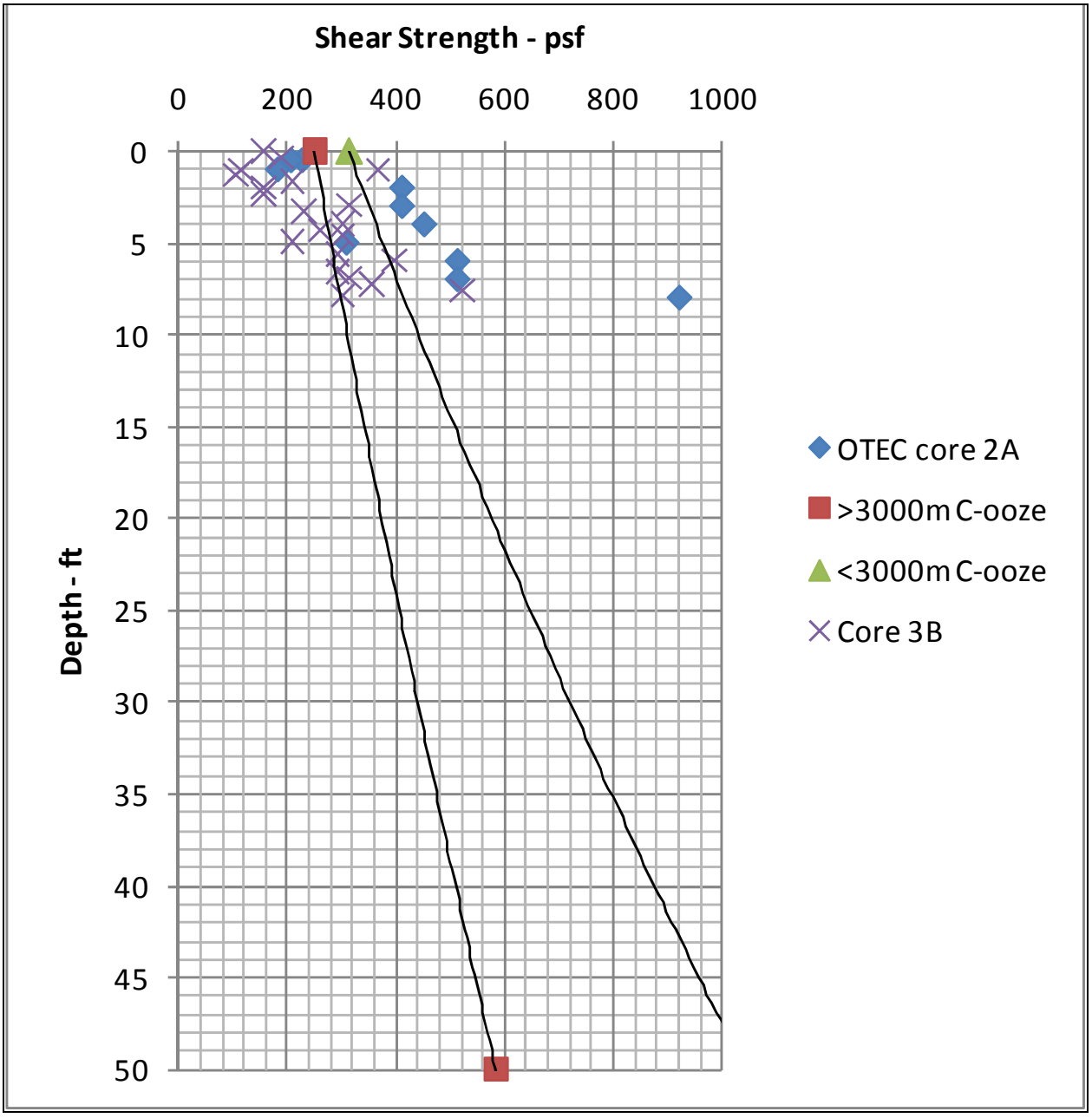


Figure 3-24. Soil Shear Strength Profiles Used for Anchor Selection [vii]

3.3.1.3 Design Trades

Platform concept selection for a 10MW Pilot Plant was performed as part of Lockheed's internal research and development program in 2008, see Table 3-6. This study resulted in the concept of separating the OTEC heat exchangers and pumps for the primary platform, and placing them on detachable modules ("Remoras"). The driving rationale for this selection was the reliability and maintainability of the heat exchangers. There is a risk that these would have to be changed,

maybe more than once, over the lifetime of a commercial OTEC facility. Having separate modules that could be detached allowed the possibility of rapid change out and minimal downtime for the servicing of the heat exchangers.

Table 3-6. Platform Key Design Trades Summary

Design Trades	Results and Rationale
Platform and Remora Configuration	Concept Select Study in 2008 picked for seakeeping and maintainability reasons.
Multi-Column Floater, Cellular Column Configuration	Fabrication in lower cost yards (does not require shipyard technology) and greater damaged stability

3.3.1.4 Topsides (A1100)

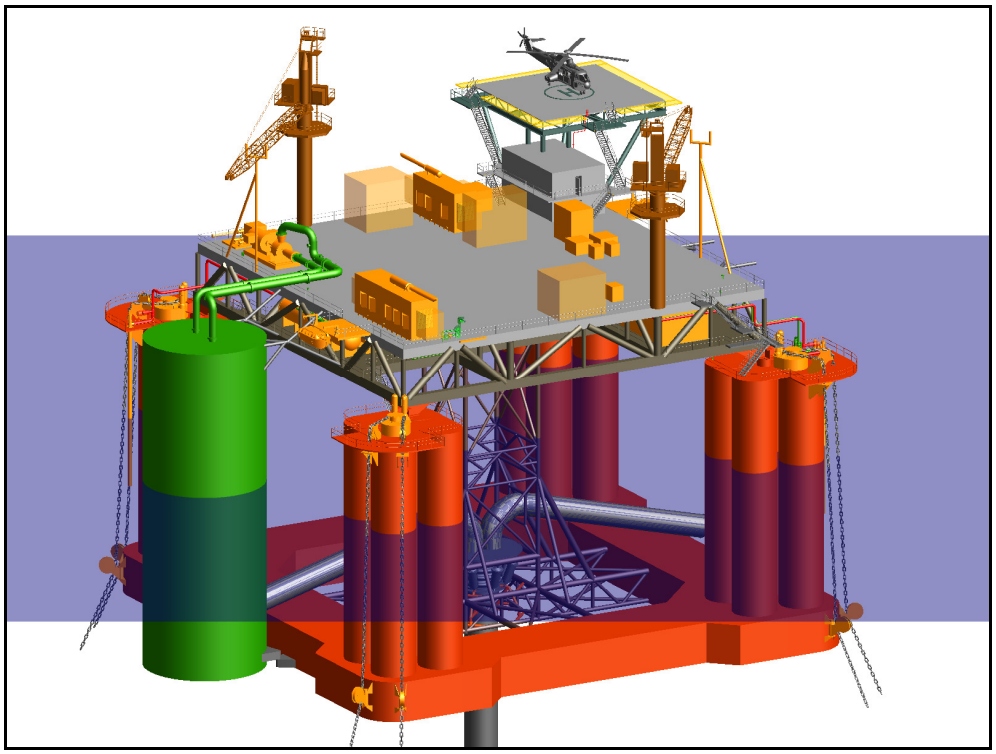


Figure 3-25. OTEC Platform

3.3.1.4.1 Introduction

This sub-section describes the platform topsides. The topsides facilities consist of:

- Two level structural deck;
- OTEC power conversion equipment and systems;

- Utility equipment and systems;
- Auxiliary/Emergency power generation and control system to support the facility;
- Instrument control system to safely control and monitor the process and utility systems;
- Living accommodations, with ancillary equipment, to support a normally un-manned facility;
- Equipment and materials to support the export power cable;
- Space to accommodate Cold Water Pipe Fabrication and hang off.
- Provide interface for Remora including structural connection and piping, electrical and instrumentation interconnects.

The following sub-sections further define the above items in process/mechanical, instrumentation/electrical and structural sections, respectively.

3.3.1.4.1.1 Platform Dimensions, Orientation and Arrangement

The platform layout arrangement is designed to meet the requirements of all three stages of operation, namely, CWP fabrication, 5 MW pilot testing, and 10 MW full productions.

The export power cable will depart the platform in a northeasterly direction. The platform has been oriented so that platform north is 50° East of True North to take advantage of the prevailing winds which are from 100° East of True North. This results in ammonia fumes being carried away from the quarters building in the event of a leak in the ammonia tanks or piping. Also, the orientation has been selected to facilitate symmetric mooring line azimuthal angles for the selected anchor locations. The personnel accommodations, control building, helideck and utility equipment are located on the north east corner so that they are located upwind from the ammonia (NH3) storage and power generation equipment.

Two cranes will be provided and will be located on the north and south sides of the platform. The key platform particulars for the two level decks are shown in Table 3-7.

Table 3-7. Platform Deck Dimensions and Elevations

Deck Level	Deck Size (m)	Elevation from Waterline (m)
Upper Deck	50 x 50	21
Lower Deck (Partial)	50 x 50	15
Top of Hull	N/A	11

The platform layout during Stage 1 – CWP fabrication is shown in Figure 3-26, and the elevation view is shown in Figure 3-27. Only one turbine generator unit is installed at the northwest corner of the platform top deck. The CWP fabrication tower and apparatus is located at the center of the platform deck. The CWP is supported by a structural frame connected to the deck and hull structure as it is extruded from the fabrication tower. At this stage, which should last only approximately two to three months, the CWP fabrication tower and apparatus, together with the CWP pipe, supplies and accessories, represent the maximum topsides payload on the platform.

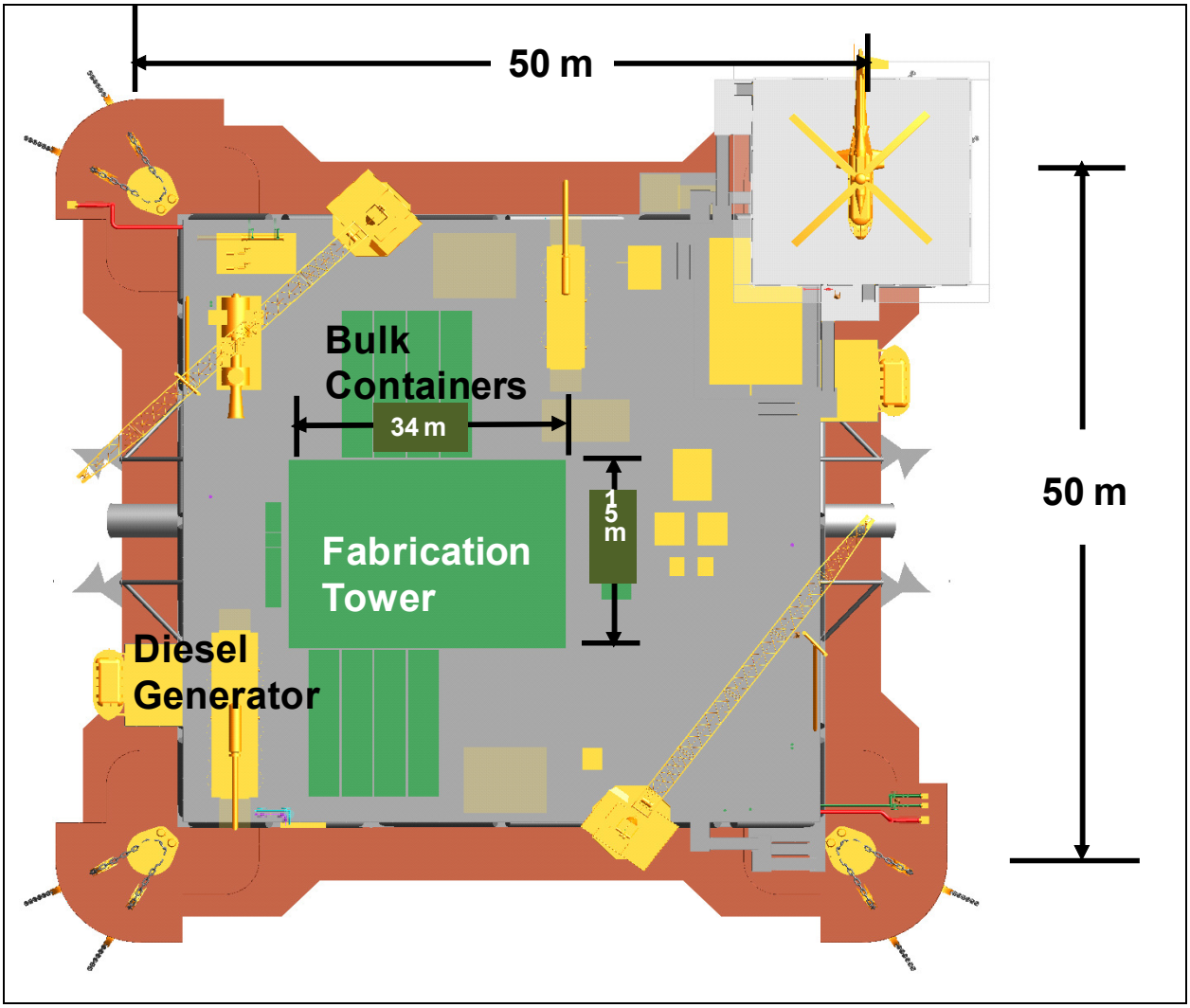


Figure 3-26. Platform Layout during Stage 1 - CWP Fabrication

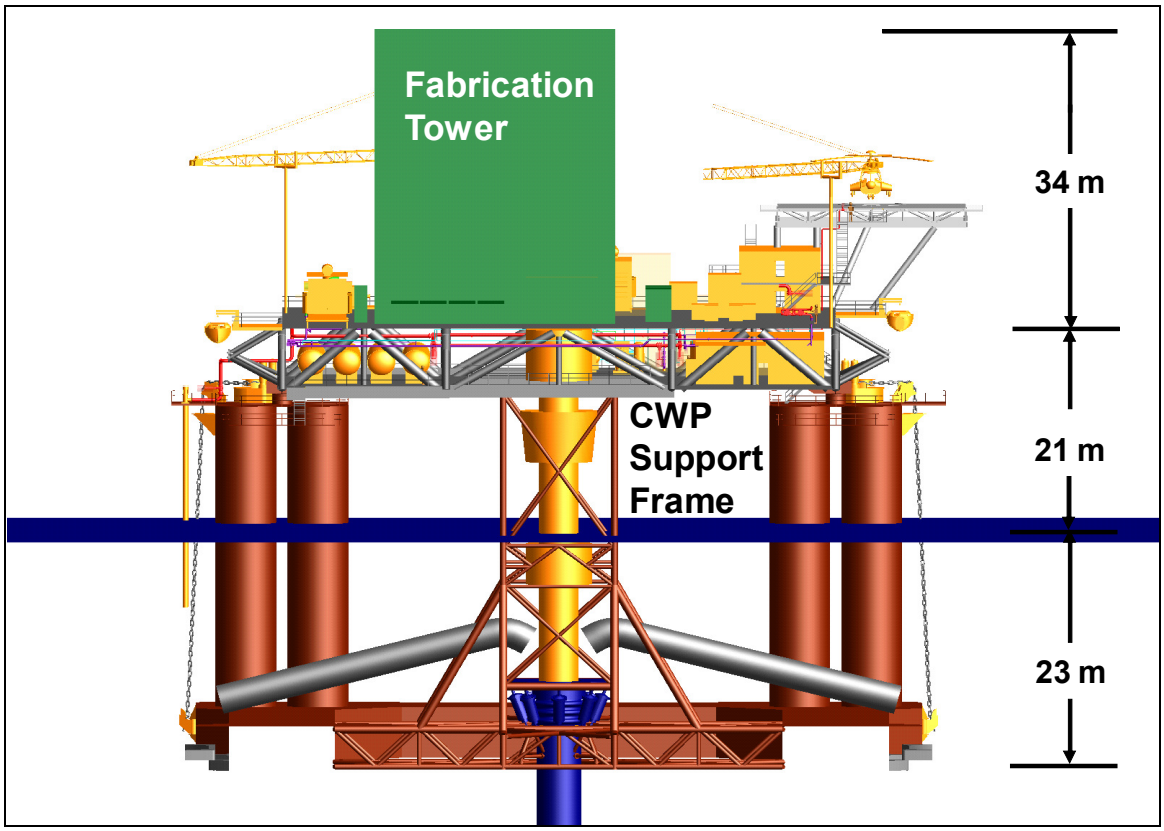


Figure 3-27. Platform Elevation View during Stage 1 - CWP Fabrication

Figure 3-28 and Figure 3-29 show the platform arrangement during the Stage 2 - 5 MW pilot testing operation. At this stage, which lasts for about two years, the CWP fabrication tower and apparatus would have been removed from the platform. One of the Remora units is brought in and attached to the west face of the platform. Connection will be made to the pre-installed ducting in the lower hull for the cold water flow, and the topsides piping to the turbine generator unit.

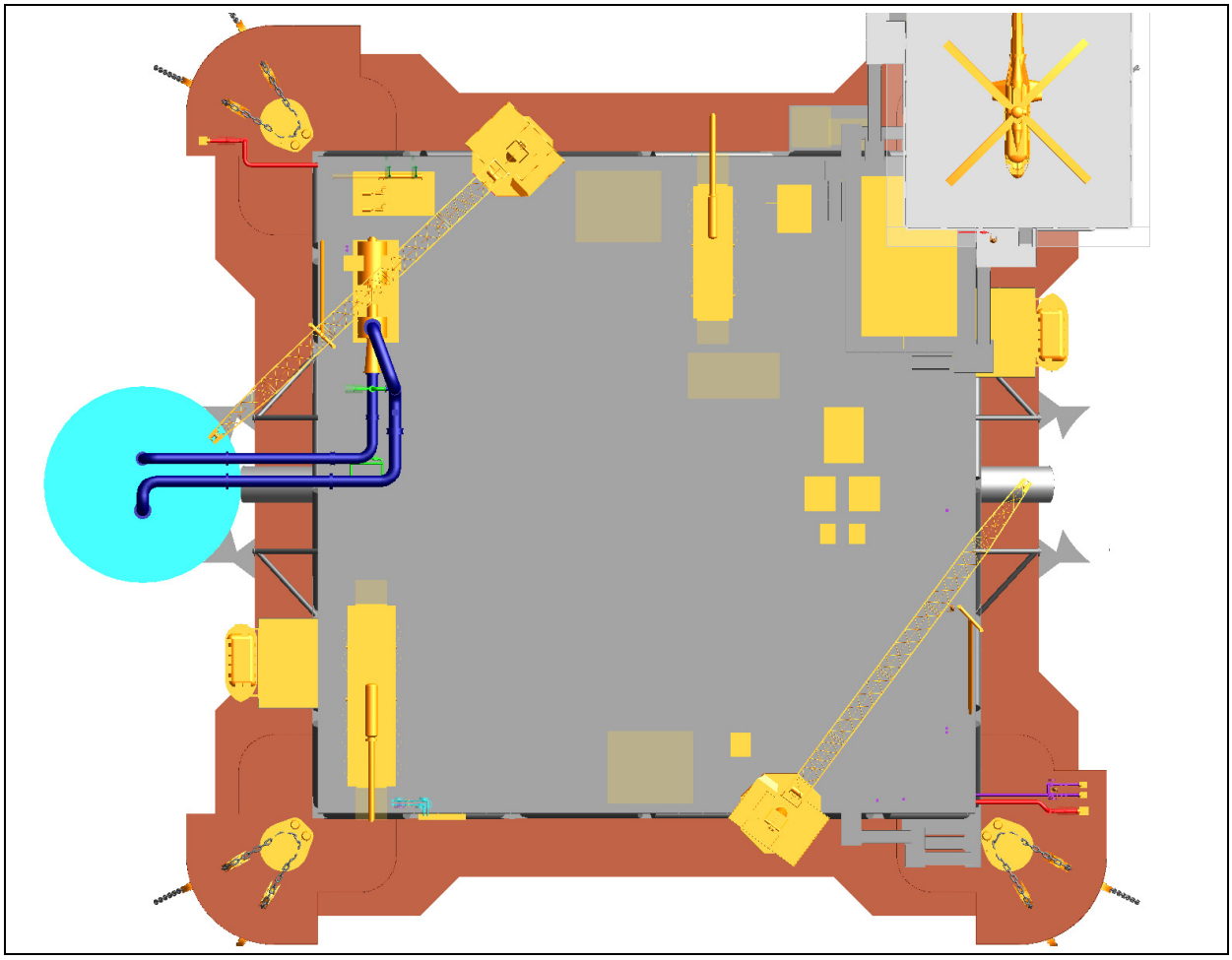


Figure 3-28. Platform Layout during Stage 2 - Pilot Testing for 5 MW Production

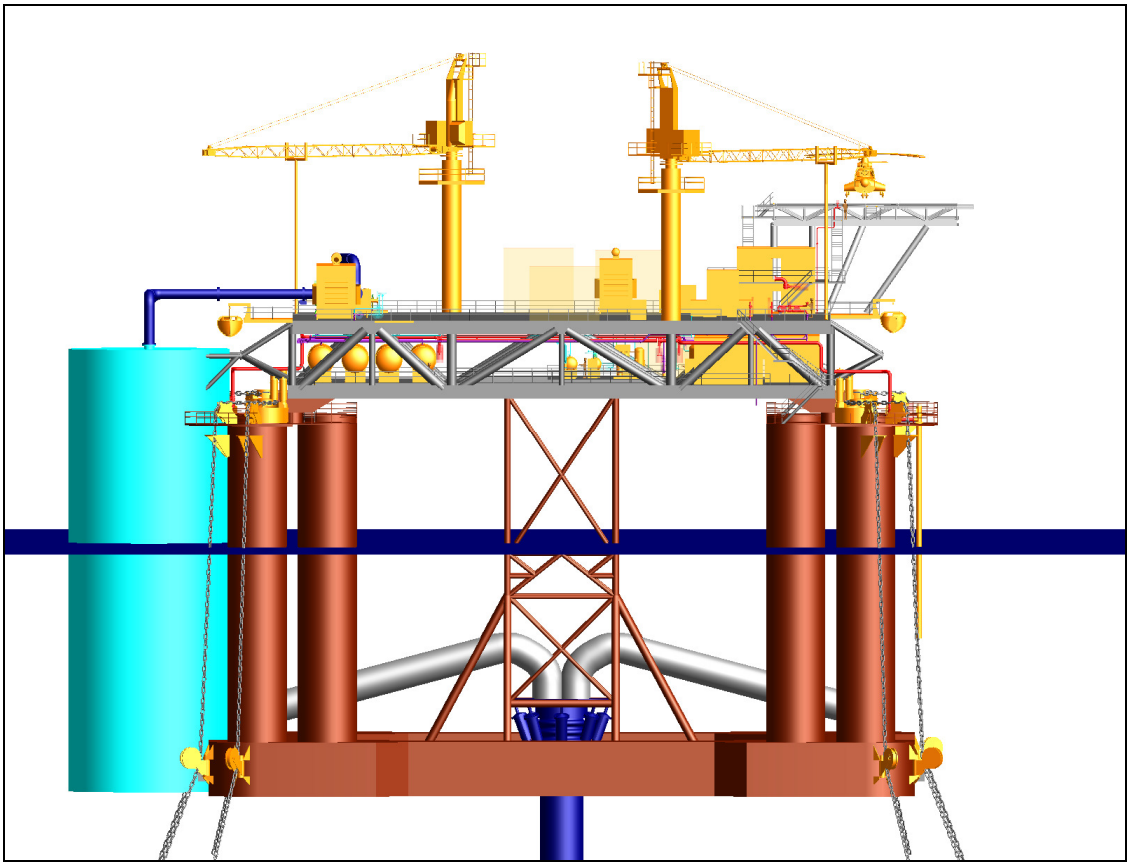


Figure 3-29. Platform Elevation View during Stage 2 - Pilot Testing

The next two figures show the platform arrangement during the Stage 3 - 10 MW full production. At this stage, which lasts for the next twenty years, another turbine generator unit will be installed at the southeast corner of the platform deck. The second Remora unit will also be brought in and attached to the east face of the platform, and connection made to the pre-installed ducting in the lower hull, and the piping at the topsides.

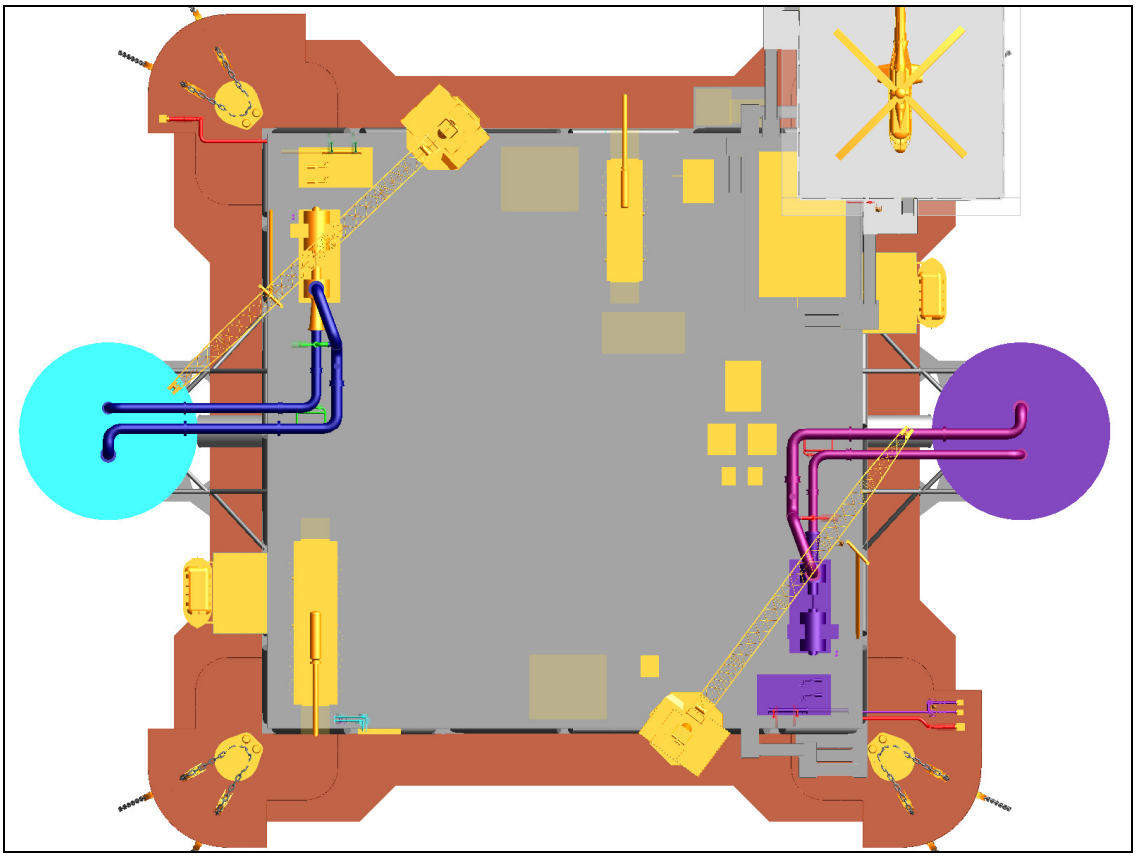


Figure 3-30. Platform Layout during Stage 3 - 10 MW Production

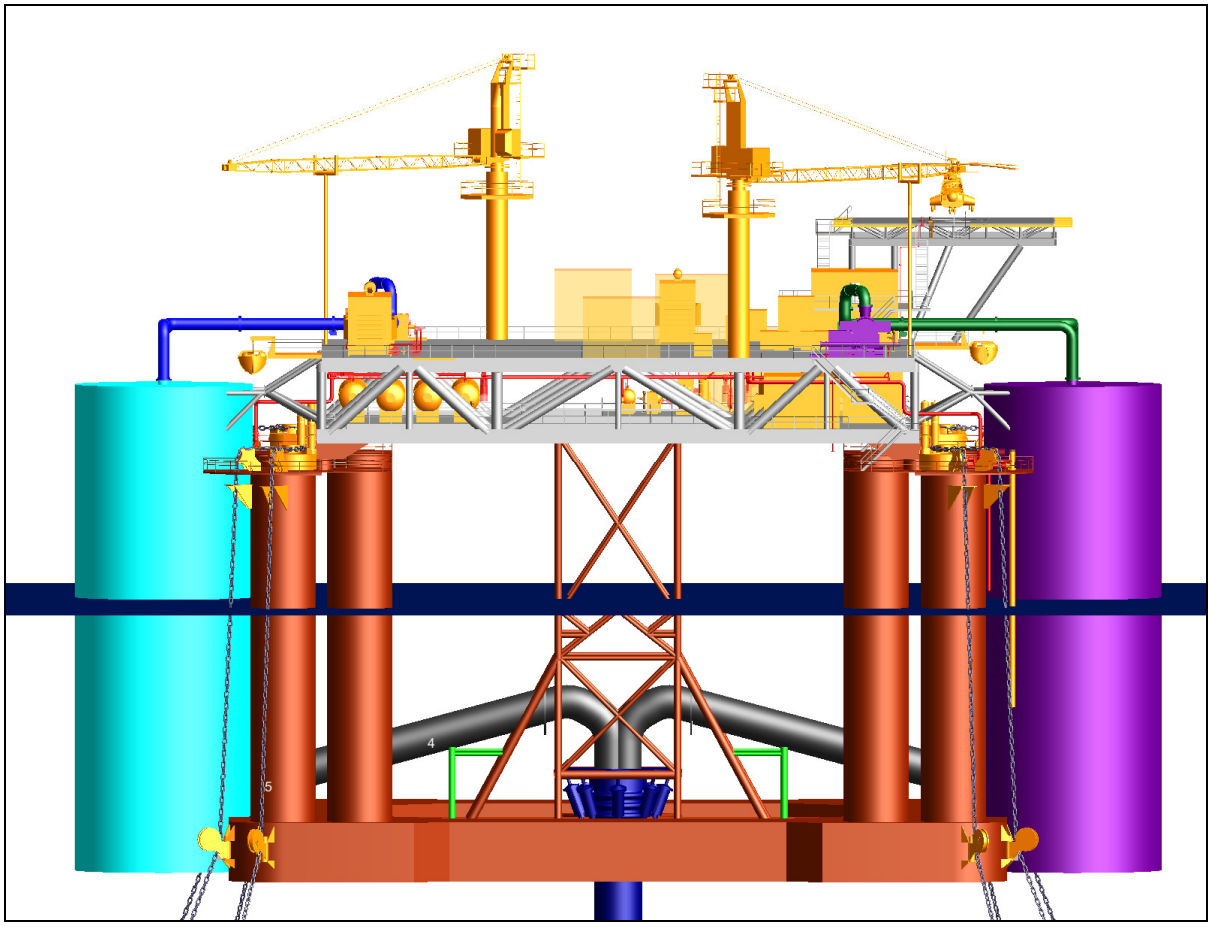


Figure 3-31. Platform Elevation View during Stage 3 - 10 MW Production

Detailed platform General Arrangement (GA) drawings for all three stages of operation are included in Appendix 3.3-1 Platform General Arrangement Drawings. The drawings for the Full Production, Stage 3 scenario are reproduced below, Figure 3-32 through Figure 3-36.

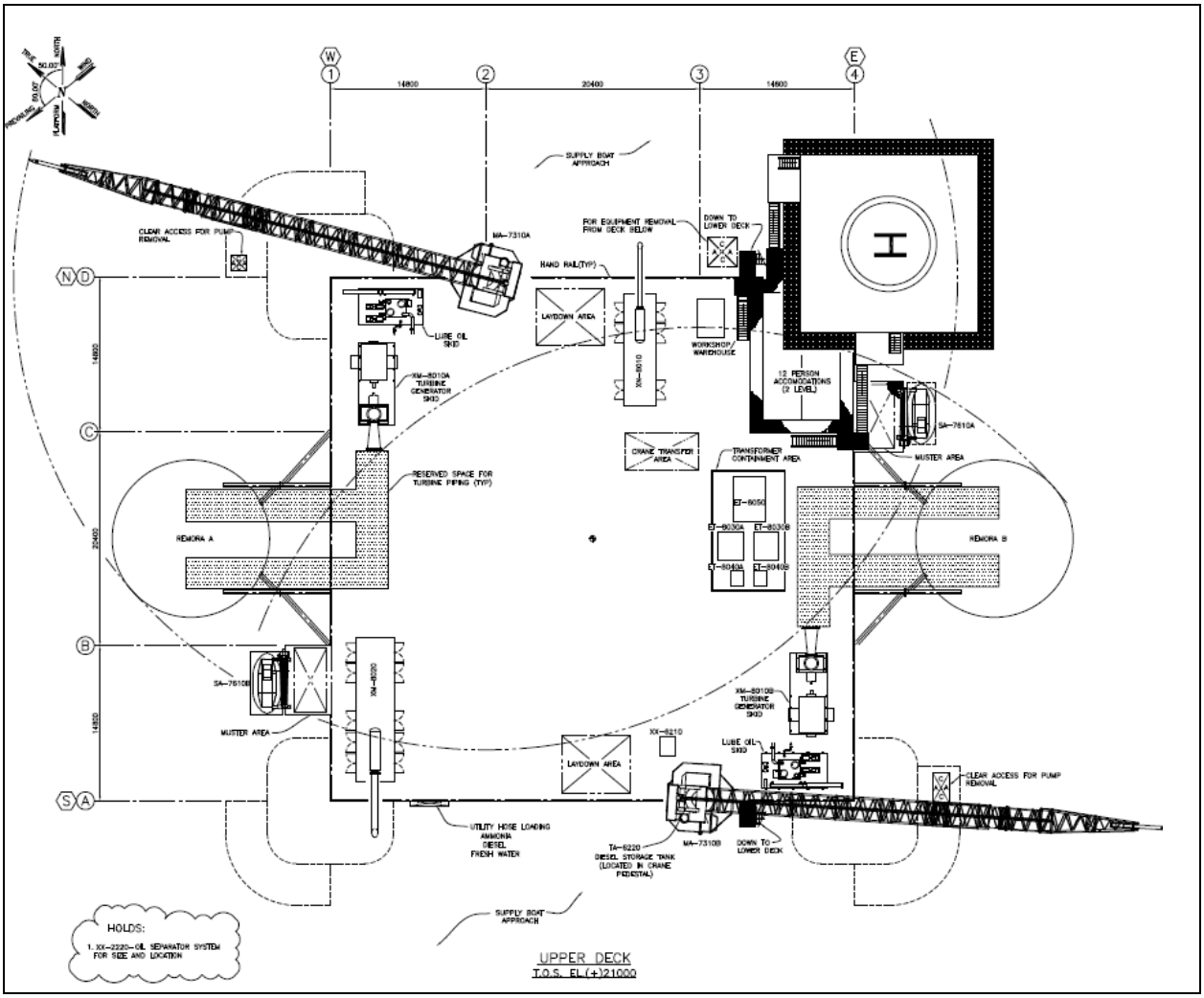


Figure 3-32. Upper Deck Plan (GA) during Stage 3 - 10 MW Production

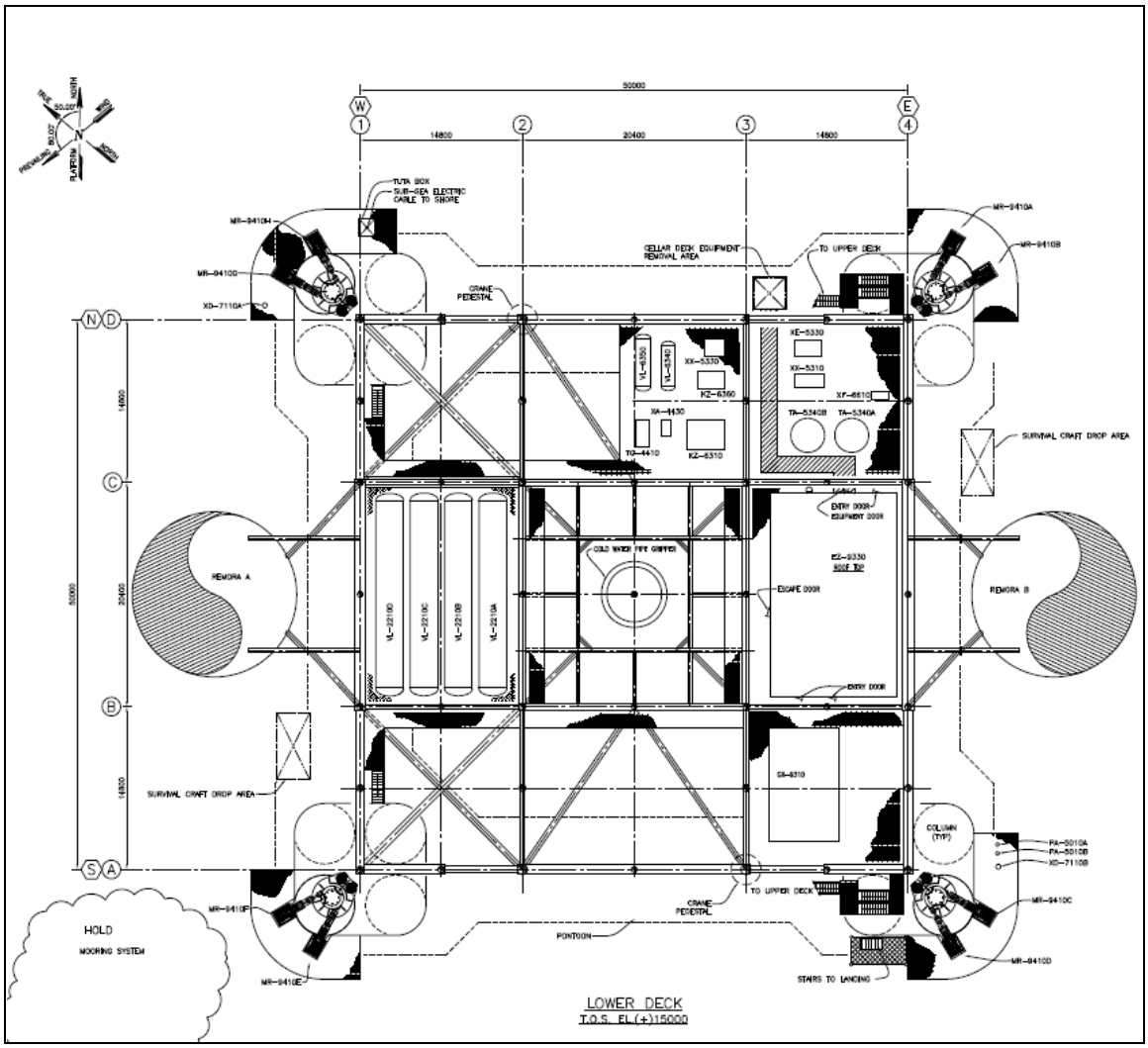


Figure 3-33. Lower Deck Plan (GA) during Stage 3 - 10 MW Production

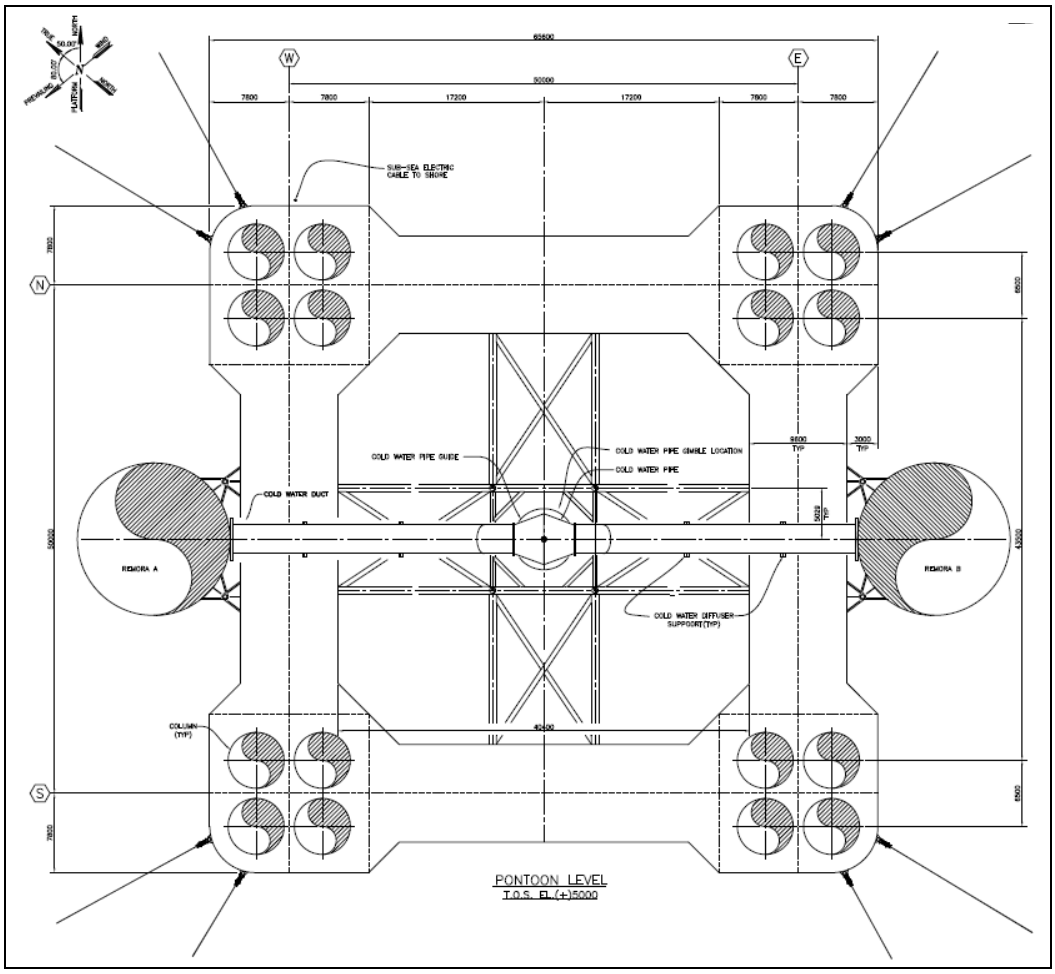


Figure 3-34. Pontoon Deck Plan (GA) during Stage 3 - 10 MW Production

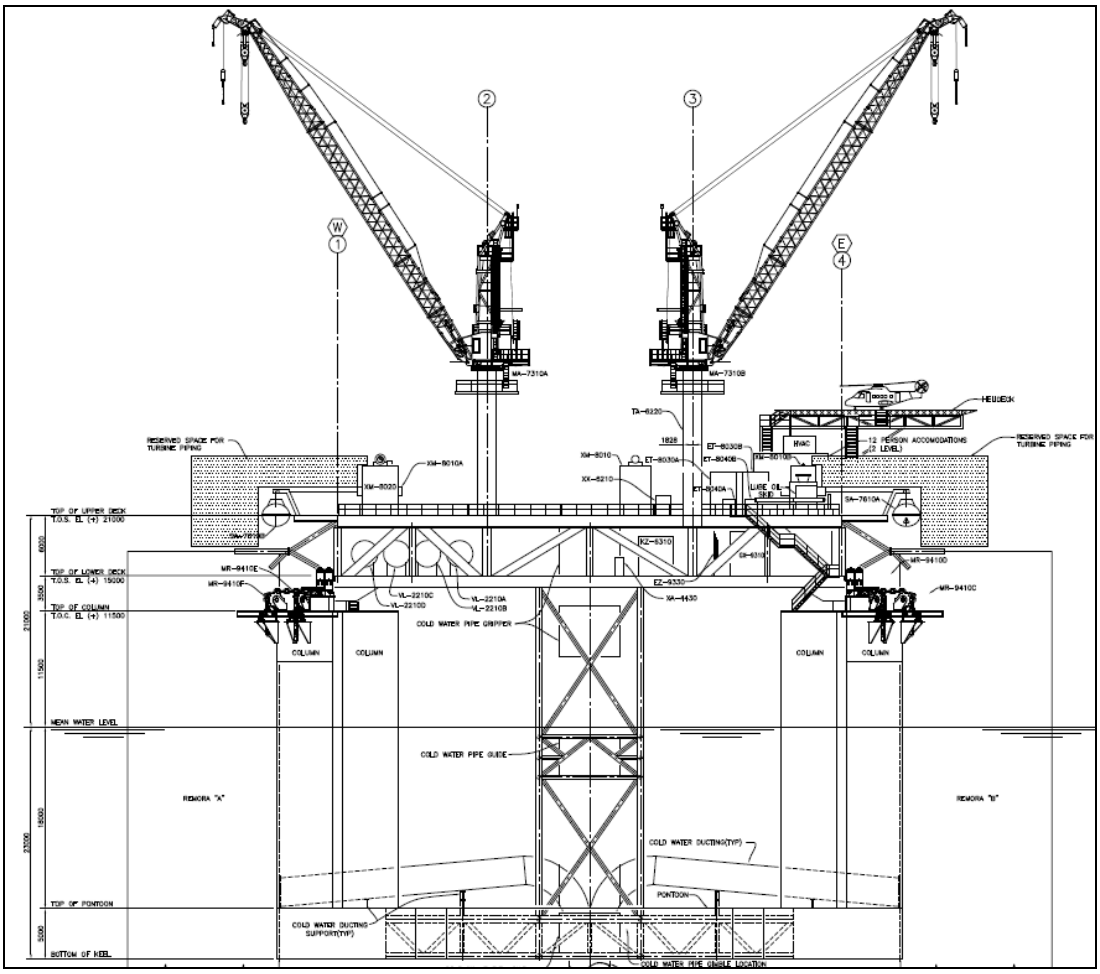


Figure 3-35. Elevation Looking North (GA) during Stage 3 - 10 MW Production

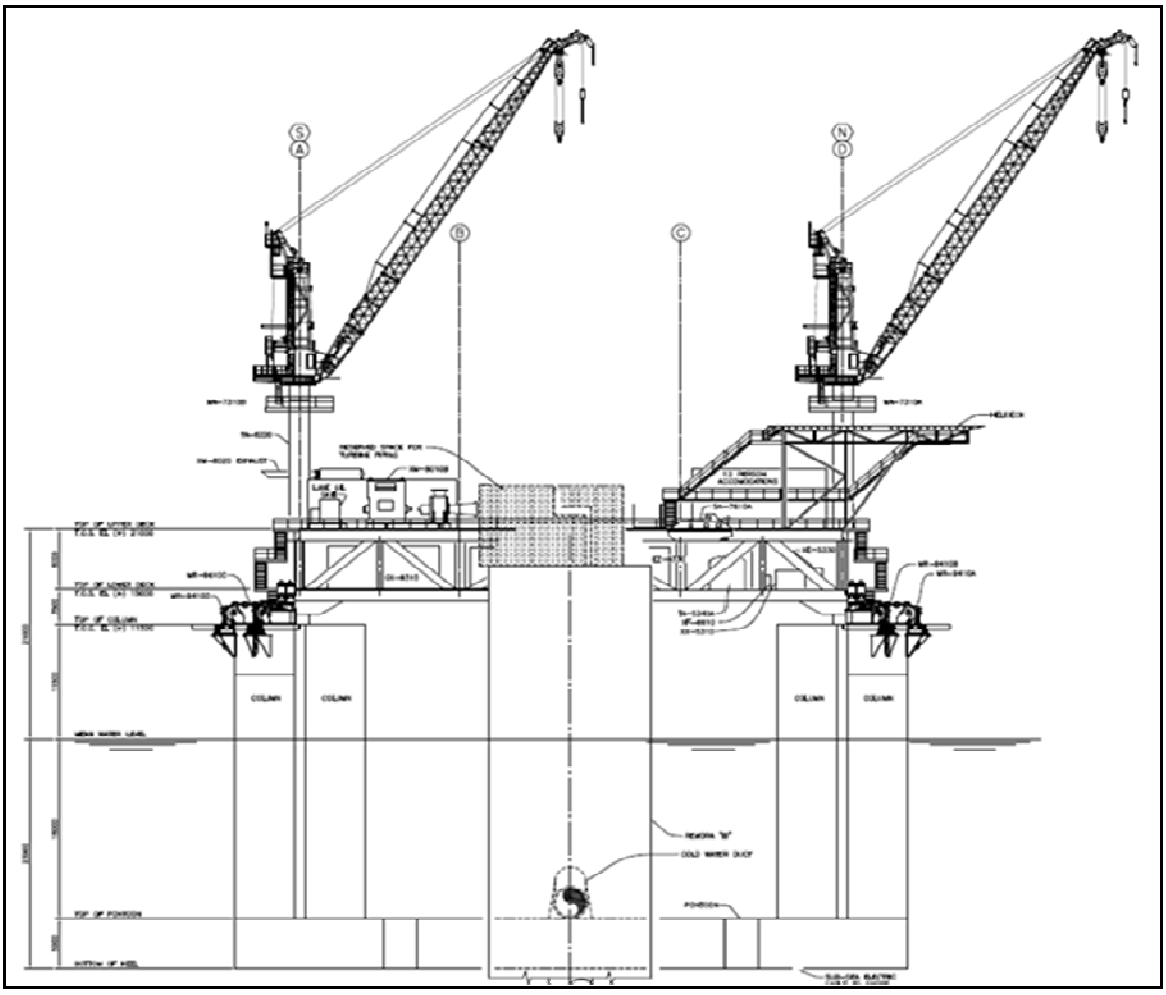


Figure 3-36. Elevation Looking West (GA) during Stage 3 - 10 MW Production

3.3.1.4.1.2 Weight Estimates

A detailed list of major topsides equipment and weight information was prepared and is shown in Appendix 3.3-2. A global weight and load report to summarize all the pertinent load cases for the platform design was prepared and included in Appendix 3.3-3. A summary of the platform weight and loads are shown in Table 3-8 for the three different stages of platform operation. The weight components include the platform deck and hull structure, topsides equipment, bulk and piping, CWP fabrication tower and apparatus. The load components include the CWP load, the cable load, and tension loads from the mooring lines. The Remora units do not add weight to the platform, as they are near neutrally buoyant. However, they added to the mass of the platform system, and attracted hydrodynamic loads from waves and currents.

The platform will have to be designed to meet the weight and load conditions of all three stages of operation, and to satisfy the requirements of the specified rules and regulations.

Table 3-8. Weight and Load Summary

	Stage 1	Stage 2	Stage 3
	CWP Fabrication	**5 MW Pilot Plant Operation**	**10 MW Production**
	(mt)	(mt)	(mt)
Deck Structure	2,164	2,164	2,164
Topsides Equipment	1,570	1,570	1,698
Topside Bulk/Piping Weight	340	340	340
CWP Fabrication Equipment (Including 7 days Staging Supply)	878	324	324
CWP/Elevation line Vertical load	352	352	352
Topsides Payload Sub-Total	**5,305**	**4,750**	**4,878**
Hull Structure & Appurtenances	6,481	6,481	6,481
Mooring Vertical Loads	404	404	807
Hull Sub-Total	6,885	7,288	7,288
Total Payload w/o Remoras/Ballast	12,189	12,038	12,166
Remora - A	-	8,042	8,042
Remora - B	-	-	8,042
Entrained Water (Incl. Trim Ballast)	**7,186**	**7,741**	**7,246**
Entrapped Water in Diffuser	261	261	261
Total Displacement (W/ Entrapped Water) w/ draft of 23 m	**19,636**	**28,082**	**35,757**

3.3.1.4.1.3 Classification/Certification

Although regulatory and classification requirements for an Offshore OTEC Facility are not yet fully defined, it has been assumed that the Platform will, in general be designed to the American Bureau of Shipping requirements.

The hull, associated hull support systems, and facility safety systems will be subject to full ABS and USCG approval. Topsides equipment or systems which generally require full ABS/USCG approval (Marine Systems) include the following:

- Primary Structure
- Electric Power Generation and Distribution
- Drains
- Diesel Storage and Supply
- Helicopter Fuel Storage and Supply
- Instrument Air (only portions of the system dedicated to support of Marine Systems)

- Buildings Housing Personnel
- Potable Water Storage and Distribution
- Sewage Treatment
- Firewater Supply and Distribution
- Seawater Supply for Hull Ballast
- Platform Cranes and Support

3.3.1.4.2 Platform Operating Philosophy

3.3.1.4.2.1 General

The facility is designed as a normally un-manned installation; however, operation of the facility, including start-ups and normal shutdowns, will normally require the presence of operations personnel.

Platform controls will consist of Programmable Logic Controller (PLC) based electronic controls. A separate electronic safety PLC will be provided for safety functions. The safety PLC and process PLC will be separate PLC's that communicate with each other. Vendor supplied PLC based controls will be based on the same manufacturer as the platform PLC. The platform PLC's will interface with Vendor PLCs, electric motor controls, flow computers, the fire and gas system panel and the page/party system to provide process data to the operators. Valves, gauges and other components requiring regular monitoring or operation will be located so as to facilitate operator access, and easy maintenance. Safety systems will be employed that are consistent with industry standard and that meet, or exceed, regulatory requirements

3.3.1.4.2.2 Manning

A two level 12-man temporary living quarters will be provided for temporary refuge of platform operating personnel. The accommodations will also provide office and conference space, galley, laundry and sanitary facilities. A remote control room in the accommodations block will allow monitoring of the platform process, utility and safety systems. The helideck will be located above the quarters and will be rated for one (1) Sikorsky S76 landing.

During construction or commissioning operations, additional personnel will be accommodated using a combination of the permanent accommodations and rented temporary living accommodations. The temporary accommodations may be powered from the topsides power generation but provide their own electrical power distribution rack. The topsides facility will contain provision to supply potable water and sewage treatment for both permanent and temporary accommodations. The design of the permanent and modular quarters will comply with all applicable ABS and USCG requirements.

3.3.1.4.2.3 Storm Philosophy

The facilities will permit the safe and expedient evacuation in the event of a hurricane/typhoon and will allow the topsides to be secured to a condition that will minimize the risk of marine pollution.

3.3.1.4.3 Safety

3.3.1.4.3.1 Navigation

Navigation lights will be provided at all corners of the platform, in accordance with USCG and maritime rules and regulations.

A navigation foghorn will be provided.

Running lights on the flare tower will be provided.

The heliport will have landing lights.

3.3.1.4.3.2 Area Classification

The degree and extent of classified locations will be based on sound engineering judgment and shall provide compliance with all recommended practices and regulatory requirements.

As there are no plans for storage or handling of materials with flashpoints below 60°C, all areas on board the platform may be considered **non-hazardous**.

3.3.1.4.3.3 Evacuation Philosophy

General

The facility design will provide for personnel protection and escape.

The placement of fire-fighting equipment and its proper use and maintenance are important for personnel protection, and will be scrutinized.

A station bill and fire control and safety plan, meeting International Maritime Organization (IMO) and USCG requirements, showing clearly all escape routes, will be posted in a highly visible location inside the quarters building.

Quarters Building

Offshore Lifeboats and/or life-rafts will be available for all personnel to utilize in the event of an evacuation.

Walkways on the exterior side of the quarters building will be located opposite the operational areas to facilitate safe egress from the quarters building.

The quarters buildings will be located as far away from the process areas as possible.

Personnel Escape Routes

The layout of production equipment will provide two paths by which personnel can escape from all normal operations areas.

The escape paths will be located so that it would be very unlikely for a single event to block both paths. Escape paths will have adequate headroom and clearance width for quick departure.

Escape paths shall be provided with emergency lighting.

Lifeboats and Lifesaving Equipment

During normal operation the facility will be provided with two 25 man (nominal) davit-launched lifeboats. The lifeboats will be sized per IMO requirements and will be dual certified as a lifeboat and rescue craft. (The exact capacity could vary slightly depending on the actual craft type and vendor selected.)

The facility will be provided with at least eight (8) ring life buoys and mounting brackets.

The ring buoys will be fitted with a water light attached to the buoy by a lanyard.

Life preservers will be provided for 125% of the personnel capacity of the facility.

The life preservers will be equipped with whistles, lights, and retro-reflective material.

The facility will be provided with at least twelve (12) hand-held rocket propelled, parachute, red flare, distress signals.

The distress signals will be stowed in a portable, watertight and non-corrosive container in a safe area of the facility.

Fire and Gas Detection

A fire and toxic gas (NH3) detection system will be provided as part of the safety shutdown system. Separate fire and gas detection will be provided in the MCC/switchgear and the living quarters buildings; however, the systems will communicate with each other and the platform control system. All buildings and enclosed areas will have fire and gas detection devices installed.

The detection, alarm and communication systems will be continuously powered and protected to reduce the likelihood that they are rendered inoperable by an abnormal condition.

Manual fire detection and alarm systems will be incorporated to complement automatic systems.

Provisions for hookup of fire and gas detection systems within the temporary construction quarters will be provided.

Toxic gas detection will be provided on the areas of the facility where ammonia is stored or used.

Public Address and Emergency Alarm System

The facility will be provided with an integrated public address and alarm system, which will provide normal and emergency facility communications. The emergency audible alarm signals shall be applied uniformly to all areas of the facility. System redundancy shall meet ABS and USCG requirements.

The emergency alarm signaling system shall be comprised of audible alarms through the public address system.

Visual alarms such as rotating beacons and/or strobe lights will be located in high ambient noise locations as needed. Such strobes or beacons shall be activated by the platform safety control system.

An audible alarm system will be provided with dual tone generators, speakers and accessories for a "Priority Tone" hierarchy as well as intercom capability.

The priority tone generator will be activated by all emergency alarms, including Emergency Shutdown (ESD), abandon facility and fire alarm. The priority tone generator will be activated by the platform safety control system.

3.3.1.4.4 Utility Systems

3.3.1.4.4.1 Ammonia

Ammonia will be stored on the platform in four (4) vessels each with an 87 m^3 capacity.

3.3.1.4.4.2 Drains / Oily Water

Deck drains will be collected and routed to a topsides oily water collection sump tank. Skidded equipment in general shall be provided with skid pan drains to the open drain system. The open drain system shall be designed to accommodate the maximum expected rainfall rate but not the maximum firewater deluge rates. The system shall have debris screens for solids removal. The open drain system shall be designed to minimize the risk of blockage and have adequate provision for flushing and mechanical cleaning. Skids shall be provided with spill containment consisting of deck plate, curbing and recessed troughs. A 2.3 m^3/h USCG and IMO approved Oily Water separator will be provided to treat the collected drains before discharge overboard.

3.3.1.4.4.3 Seawater

Two (2) 340 m^3/h submersible type seawater lift pumps will be located in external caissons. Each seawater lift pump will be capable of supplying the cooling water demands of the generators, lube oil skids, and will also supply the hull ballast system.

A sanitary pressure set will provide sanitary water to the accommodations.

3.3.1.4.4.4 Potable Water

Potable water will be generated on the platform using a 19m3/d reverse osmosis unit. Two 19 m^3 potable water storage tanks will be provided, along with a pressure set to service the accommodations, platform utilities and safety shower / eyewash system.

3.3.1.4.4.5 Diesel System

Diesel storage capacity will be provided in the north and south crane pedestals. Each pedestal will be designed to store 37 m^3 of diesel. A particulate type loading filter will be provided to remove sediment from the boat storage. A coalescing filter will be installed downstream of the diesel transfer pump to remove residual water in the fuel supply. Additionally, the transfer pump

may be used to circulate diesel from the crane pedestals through the coalescing filter for diesel cleanup.

3.3.1.4.4.6 Compressed Air

A compressed air system will be provided to supply instrument and utility air at a suitable water dew point. Two 100% capacity rotary screw compressors, dryer and receiver shall be installed to serve process and marine systems needs. Pressure control regulators shall be configured to assure precedence of air supply to the instrument air header versus utility/starting air requirements.

3.3.1.4.4.7 Sewage Treatment

The accommodation will be provided with an electrochemical cell type marine sewage treatment unit to grind and treat solids for 14 personnel (black water only). The discharge shall contain no floating solids and minimum 1 mg/l residual chlorine and meet USCG regulatory requirements.

3.3.1.4.4.8 Fire and Safety

The platform will be provided with two 100% firewater pumps, 114 m^3/h each (nominal, to be confirmed) and hose reels. Two 25-men (nominal) escape crafts, life rafts, life rings, life jackets, portable fire extinguishers, litter, etc. will be provided per ABS and USCG requirements. The exact capacity of the escape crafts could vary slightly depending on the actual craft type and vendor selected.

3.3.1.4.4.9 Cranes and Material Handling

Two platform cranes will be provided: one on the north side of the deck and the other on the south side.

Use of the cranes during initial construction, hookup and commissioning and future construction work (CWP fabrication equipment removal) will be limited to the capacities of the cranes listed below. Lifting of construction items or future equipment items weighing in excess of the crane capacities listed below will be accomplished by other methods, such as the use of temporary platform rental crane or derrick barge.

Crane specifics are below: North Crane Location – Column Row D-2 Model – Seatrax Model S7220 or equivalent Boom length – 42.7 m Capacity – 25,850 kg at 26 m onboard lift (to be confirmed). South Crane Location – Column Row A-3 Model – Seatrax Model S7216 or equivalent Boom length – 42.7 m Capacity – 19,950 kg at 26 m onboard lift (to be confirmed) Boom rests will be provided at the appropriate location for both cranes. Diesel storage of 45 m3 will be provided in each crane pedestal.

3.3.1.4.4.10 Helicopter Refueling

No helicopter refueling will be required on the platform.

3.3.1.4.4.11 Heat Ventilation and Air Conditioning (HVAC)

The quarters building will be environmentally controlled with a suitable zoned HVAC system. Two 100% condenser units will be located on the quarters roof under the helideck. The MCC building will also have a zoned (or parallel unit) Heating Ventilation and Air Conditioning (HVAC) system.

3.3.1.4.4.12 Piping and Instrumentation Diagram (P&ID)

Piping and Instrument Diagrams for all topsides systems are included in Appendix 3.3-4.

3.3.1.4.5 Additional Design Requirements

3.3.1.4.5.1 Piping

Ammonia process piping will be designed in accordance with American Society of Mechanical Engineers (ASME) B31.3. Marine system piping must be designed in accordance with ASME B31.1.

All vessels and equipment requiring maintenance isolation must be equipped for positive isolation from pressure sources. Isolation for vessels subject to manned entry shall consist of double block and bleed arrangements, blind flanges, or provision for installation of isolating blinds. All threaded ball valves shall have 316L SS bodies, handles and trim. Utility system piping drops from headers, 1" and smaller, shall be run in 316 SS tubing rather than pipe. Piping flange and support bolting shall be fluorocarbon coated. Consideration shall be made for small diameter piping in vibrating service (i.e. reciprocating compressors or pumps) to be socket welded.

Basket, Y-type or cone strainers shall be installed upstream of equipment subject to plugging or damage by the entrance of solids. Strainer differential pressure indicators shall be installed in critical services.

3.3.1.4.5.2 Materials Selection/Corrosion Control

To meet the design life of the facility, general piping material requirements are as follows:

- Ammonia and general piping: Carbon steel, American Society for Testing and Materials (ASTM) A106 Gr. B
- Seawater piping: Fiber Reinforced Plastic (FRP) or 90-10 CuNi to meet the requirements of USCG Policy File Memorandum (PFM) 1-98
- Potable water: 316L stainless steel or Polyvinyl Chloride (PVC)
- Compressed Air: 316L stainless steel
- Open drains: FRP
- Carbon steel and stainless steel piping shall be coated per Project specifications.

3.3.1.4.6 Sparing Philosophy

Rotating equipment (pumps, compressors) in critical or important services shall be spared or otherwise configured as parallel units to allow uninterrupted operation. See Platform Master Equipment List in Appendix 3.3-2 for more details.

3.3.1.4.7 Instrumentation and Controls

Platform control is divided into multiple independent systems. A schematic diagram of the Central Control Room system is shown in Figure 3-37. Separate PLC processors shall be used for each system. The platform Integrated Control and Safety System (ICSS) will consist of the following major subsystems:

- Facility Control System (FCS)
- Ballast Control System (BCS)
- Fire and Gas Detection System (FGS)

Each major subsystem shall have local I/O, communication interfaces, local Operator Interface Panels with remote I/O, and a Human Machine Interface (HMI) system. Vendor supplied Programmable Logic Controller (PLC) based controls shall be based on same manufacturer as the ICSS. The ICSS shall interface with local transmitters, vendor PLCs, electric motors, flow computers, fire and gas systems and the Page/Party system to provide data for operator's information on process status.

3.3.1.4.7.1 Integrated Control and Safety System (ICSS)

The ICSS will use PLC processors.

PLC processors will be located in a Master Control Panel (MCP) in the Electrical Building.

Human Machine Interface (HMI) monitors will be located in the Central Control Room located in the Electrical Building and the Bridge Control Room in the Living Quarters Building.

Local Control Panels (LCPs) will be located throughout the process areas.

The LCPs will have separate remote I/O components for the FCS, and BCS subsystems.

The LCPs will have a thin client operator terminal and pushbuttons to provide operator interface to the process.

All alarms may be acknowledged and reset from either an LCP Panel or from a control room HMI station.

Remote I/O PLC and thin client components in the LCPs will be linked to the MCP by fiber optic data link cable.

Turbine Generator control panels will be located in the Electrical Building.

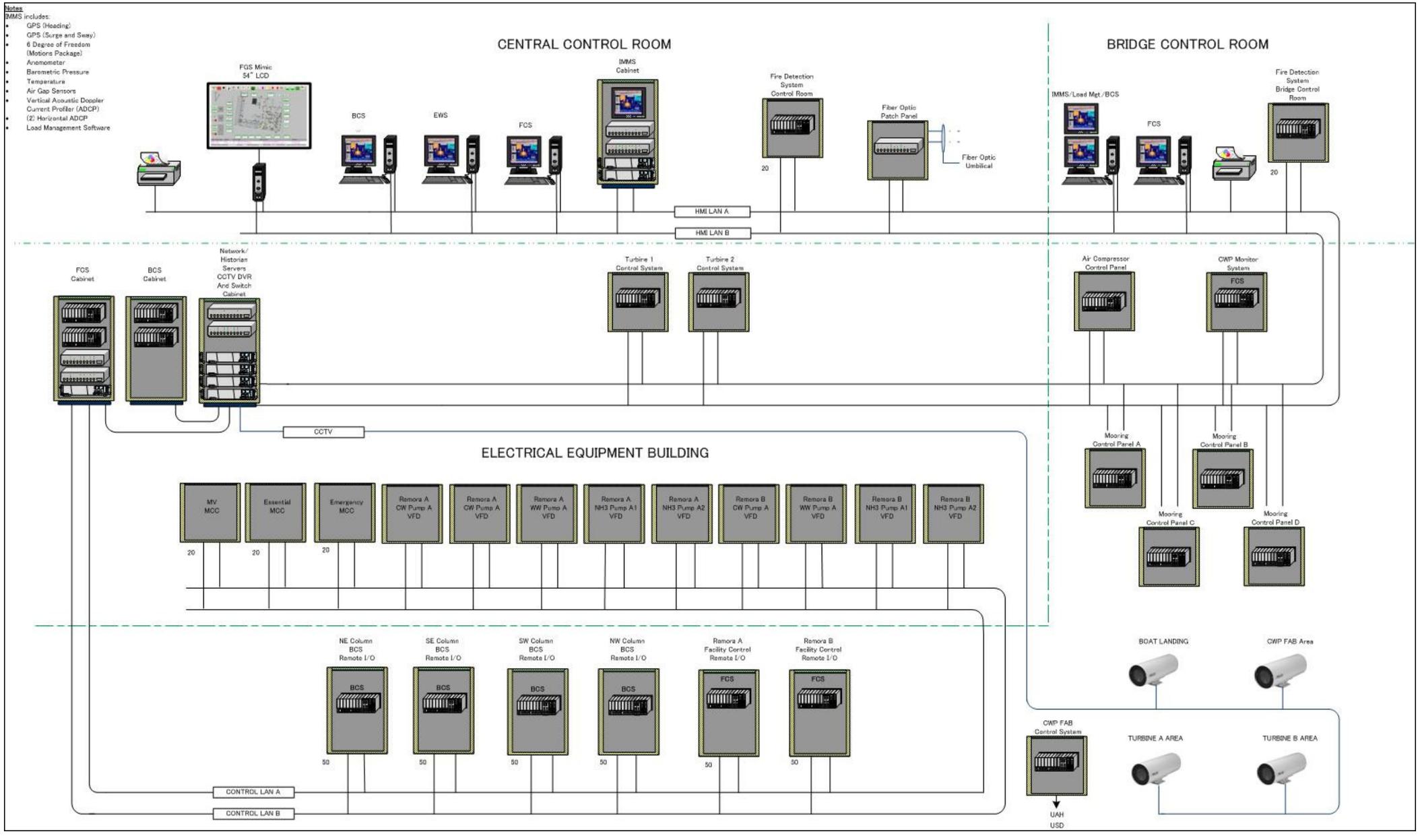


Figure 3-37. Schematic Diagram of Platform Central Control Room

3.3.1.4.7.2 Vendor Panels

Certain vendor packages, such as Turbine Generators, Firewater Pumps, Sewage Treatment Unit, and Air Compressor skid will be equipped with self-contained PLC control systems. Each skid control PLC will have annunciation and testing capabilities so that testing of the unit is independent of the other platform processes. The skid PLCs will be linked to the ICSS by Ethernet to provide monitoring of process conditions. In addition, the skid PLCs will be hard wired to the platform central PLCs to provide an indication of process shutdowns and alarms independent of the Ethernet link.

Vendor packages contain safety and control under one control system.

3.3.1.4.7.3 Facility Control System (FCS)

The FCS consists of redundant control processors and remote I/O components located in the local panels.

The FCS will contain the logic to start/stop pumps, throttle control valves, initiate turbine start commands and monitor motor status.

The FCS will use transmitters for level, pressure and temperature sensing. Proportional Integral Derivative (PID) control will occur in the Process Control System (PCS) with output to the local final control elements.

Electronic level measurement shall be a magnetically coupled type with external float tube and float indication.

All motor manual operators shall send an input to the PLC to initiate a start operation. Motors shall provide a run status to the PLC.

ESD pushbutton stations shall be located at key egress points throughout the platform. An ESD pushbutton shall initiate an alarm and Process Shutdown (PSD). The ESD pushbutton stations will be electronic.

3.3.1.4.7.4 Ballast Control System (BCS)

The BCS consists of a control processor and remote I/O components located in the local panels.

The BCS will contain logic to start/stop ballast and bilge pumps, open/close ballast valves and monitor ballast tank levels and leak detection sensors.

Control of the BCS shall be selectable from either the Central Control Room or the Bridge Control Room.

3.3.1.4.7.5 Fire and Gas Detection System

The FGS will consist of dedicated fire panel designed and certified to meet NFPA 72 requirements and in accordance with USCG regulations, flame detectors, gas detectors and hard-wired interface with the Living Quarters Fire Panel.

Buildings and other normally inhabited areas will be protected in accord with USCG regulations and National Fire Protection Association (NFPA) 72 through use of approved fire detection systems including, smoke and thermal detectors, manual pull switches, HVAC ducting controllers, fire and gas marshalling /control panel, etc.

The Living Quarters Fire Panel shall monitor smoke detectors, fire sensors, gas detectors, and pull stations located in the living quarters.

Auxiliary Building Fire Panels shall be located in other non-quarters normally inhabited areas. These panels shall monitor smoke detectors, fire sensors, gas detectors, and pull stations for these buildings. The Auxiliary Building Fire Panels shall operate independently of the Living Quarters Fire Panel and shall be connected via Ethernet to the Living Quarters Fire Panel for monitoring and alarm.

All fire panels shall have hard-wired alarms going to the FCS. The alarms will indicate trouble, controller failure, firewater flowing, firewater valve tamper switches, type of fire alarm (i.e. smoke, thermal, manual pull) and the floor that the alarm occurred on.

All executive actions shall be performed by the FCS.

Enclosed equipment spaces such as enclosures for turbine generators, turbine compressor drivers, emergency generator, and auxiliary generator shall be equipped with fire detection systems and suppression (CO2 or FM-200) flood systems. Occupied spaces such as the control room, switchgear room, communications room, and Uninterruptable Power Supply (UPS) room will utilize a USCG approved suppression system.

Process areas on the decks will be protected by a pneumatic fusible plug system for fire protection and the use of gas detection devices in open areas.

3.3.1.4.7.6 Other Systems

The hull provider will provide an Integrated Marine Monitoring System (IMMS) and mooring monitoring systems. These systems will be engineered and installed by others (e.g. hull contractor). Space will be allocated in the Central Control Room for the IMMS and mooring control station. These systems will interface with the platform ICSS such that status information can be monitored via the HMI.

3.3.1.4.7.7 Motor Controls

Platform process motors, in general, shall have two interposing relays for each motor.

One interposing relay shall be used to shutdown the motor based on safety shutdown event.

One interposing relay shall be utilized control logic to start and stop the motor.

Electric heater controls shall follow the same logic as the motors; however, heater process control logic shall be by the electric heater vendor.

Motors controlled by Vendor PLC logic such as Turbine Generators and Air Compressors shall be controlled only by the vendor panel and shall not have control logic within the platform ICSS. The vendor panel shall start/stop the motor and monitor the motor status.

3.3.1.4.7.8 Field Instrumentation

Where required for maintenance, actuated control valves and shutdown valves shall have upstream and downstream isolation valves, and vent/drain valves as required.

Pressure Safety Valves (PSVs) shall be equipped with process isolation valves as applicable and inlet pressure test connections.

Level controllers shall be externally caged as standard practice.

Pressure alarms and shutdowns shall use electronic transmitters.

Level alarms and shutdowns shall use electronic transmitters.

Liquid dump valves shall be sized to properly process the entire range of expected operating conditions.

3.3.1.4.8 Electrical Systems

3.3.1.4.8.1 Essential Power Generation

The electrical system shall be designed in accordance with the relevant requirements of the USCG and ABS for classification.

The Essential generator shall be a 100% capacity diesel engine with a 13.8kV/3/60Hz generator.

The Essential generator shall be designed for continuous synchronous operation.

13.8kV / 4160V transformers shall be provided along with main-tie-main 4160V switchgear to supply Medium Voltage (MV) pump motors between each Remora.

13.8kV / 480v transformer shall be provided along with a main-tie-main 480V Switchgear to Emergency MCC bus.

Switchgear circuit breakers shall be 125 VDC electrically operated.

Resistance grounding systems shall be provided on medium (low resistance ground) and low (high resistance ground) voltage systems. .

3.3.1.4.8.2 Emergency Power

A diesel engine-driven emergency generator set shall be provided to maintain emergency electrical loads such as critical life support, control, and utilities, when the main generators are shut down, as defined by regulatory and ABS classification requirements.

The emergency generator set and associated switchgear and controls shall be segregated from the other electrical systems in accordance with USCG requirements. .

The emergency generator set shall start automatically upon the essential generator failure and shall supply a dedicated emergency distribution system.

The emergency generator set shall have a dedicated independent start capability to allow black start. The start system shall be sized in accordance with ABS/USCG requirements.

The emergency generator set shall be capable of routine test starting with the main generator in use, and shall have the capability for synchronization, as allowed by the certifying authority, for bumpless transfer. The emergency generator shall not be capable of parallel operation with the main or essential generators.

The emergency generator set shall have an 18-hour day tank for continuous self-contained operation. However, the platform diesel supply system will maintain sufficient fuel for a minimum of four days of unattended continuous operation in event of storm evacuation.

3.3.1.4.8.3 Electrical Distribution

The 13.8kV switchgear shall supply the two 4160V liquid filled and one 480V dry transformers.

The main 480V distribution panel shall feed the majority of the process and utility power users and transformers for the low voltage distribution systems.

System status shall be monitored by a power management system that shall shed loads in case of approaching overload to prevent "blackout" conditions.

The equipment providing service for the normal platform electrical loads shall be located within the electrical equipment building.

Institute of Electrical & Electronics Engineers (IEEE) 45 cable shall be used for all topsides interconnect for outdoor services. Conduit shall not be used for these services.

Separate Direct Current (DC) distribution will be provided for emergency lighting, emergency switchgear, generators, compressors, navigation aids, instrument control system and instrument safety system.

Separate UPS systems to be provided for instrumentation, communications and subsea systems.

Cable penetrations into A60 or H60 fire-rated building walls and floors shall utilize ABS approved transit system.

Electrical distribution shall follow the following guidelines:

- Motors 250 Horse Power (HP) (186 Kilowatts (KW)) and larger 4160 (Volts Alternating Current (VAC)
- Motors 200 HP (149 KW) and smaller 480 VAC
- General lighting ..... 208/120 VAC
- Switchgear control power… ..... 125 VDC (Volts Direct Current)
- DC systems ..... 24 VDC

3.3.1.4.8.4 Emergency Power

A 24 VDC battery system shall provide power to critical loads. The system shall include battery chargers; low voltage monitors and disconnect switches located in an enclosed safe area.

The navigation aids system shall be provided with a separate 24 VDC battery system.

A 208/120 VAC, 3-phase, 4-wire UPS system shall be provided to power the required lighting for platform evacuation and other essential loads. The UPS shall draw on the 125 VDC battery bank upon loss of normal and emergency power.

3.3.1.4.8.5 Lighting

Facility lighting shall include provision for emergency lighting of access/egress areas, the electrical equipment building and the accommodation module.

All decks and process areas shall be designed with 24-hour illumination.

3.3.1.4.9 TELECOMMUNICATIONS

3.3.1.4.9.1 Platform Radio and Telephone

A system shall be provided for communication with land-based networks. Others will provide this system, but space will be provided for installation of the equipment.

A platform GAI-Tronics or equal multi-channel intercom system (local telephone network) shall be provided.

The platform cranes will have a link to the multi-channel intercom system to allow the crane operator intercom and telephone functions.

3.3.1.4.9.2 Marine and Aeronautical

Radio will be provided for communication with supply boats, shipping, and helicopters. Others shall provide the radio system, but space will be provided.

3.3.1.4.9.3 Telemetry

A Supervisory Control and Data Acquisition (SCADA) system will be provided for acquisition of facility information, furnished by others.

A communications link will be used for platform phone, fax and platform PLC data.

3.3.1.4.9.4 Electrical and Control System Diagram Drawings

The following drawings are included in Appendix 3.3-5:

(1) Electrical Single Line Diagram

(2) ICSS Architecture Diagram (Sketch)

(3) IMMS Block Diagram

(4) Electrical Equipment Room Layout

3.3.1.5 Platform Structure (A1200)

3.3.1.5.1 Hull Structure

The hull structure provides the buoyancy and stability to support the topsides, remoras, cold water pipe and the electrical power cable. The driving requirements for the platform were discussed above, see Table 3-2. Key interfaces include:

- Topsides to column interface
- Remora Interface
- CWP Interface

The topsides were discussed in the previous section. A key principle of this design is to place virtually all of the equipment for OTEC and utilities on the topsides in order to keep the hull outfitting as simple as possible. This minimizes the cost of the hull.

The remora will be attached to the platform at the pontoon level and the deck level. Global structural analysis including the remoras was performed as part of this study to verify the connector loads.

The bracing for the CWP support structure has been sized to carry the maximum survival loads, and also to achieve the minimum stiffness values dictated by the requirements for fabrication of the pipe. This is discussed in the companion report on Technology Development [i]

As discussed above, the semi-submersible hull form was selected for the pilot plant because of the motion requirements of the CWP, particularly during fabrication. The hull form selected for this study is the Multi-Column Floater (MCF) developed by Horton Wison Deepwater (HWD). The OTEC MCF concept is illustrated in Figure 3-38. This differs from a conventional semi-submersible primarily in the configuration of the columns. Each "column" consists of four cylinders, as opposed to a monolithic stiffened shell type structure. The advantages of this arrangement include:

- Lower hull fabrication cost (reduced labor and steel wt)
  - Columns can be fabricated in fabrication yards vs. shipyard
- Pontoon configuration provides lower vessel response to environment
- More stable vessel:
  - In damaged hull event because of increased number of compartments
  - Unconditionally stable

Lower Hull Fabrication Costs

The cylindrical "cells" used to make up a column are fabricated as rolled plate with ring stiffening. There are no longitudinal stiffeners which complicate the fabrication of a typical cross stiffened plate type structure. These conventional structures require shipyard techniques such as panel lines to fabricate the plates, which must be assembled into the hull structure. The rolled, ring-stiffened cylinders may be fabricated in low cost fabrication yards.

Lower Vessel Response to the Environment

The pontoon and column arrangement of the MCF has been optimized to provide minimum heave and pitch motions. This is accomplished by selecting the optimum pontoon dimensions along with the column dimensions to result in cancelation of the hydrodynamic forces acting on the columns and pontoons.

Increased Stability

Damage stability of the MCF is enhanced by the large number of compartments in each "column". Each of the cells included three void spaces, making 12 voids per column. Also, the MCF does not have downflooding points at the top of the cells thus making the hull unconditionally stable even at high inclination angles. This is illustrated by Figure 3-39 which shows the righting and overturning moment curves for a typical semi-submersible and the MCF. A typical semi-submersible has a downflooding point and range of stability determined by the point at which the righting moment is negative. The MCF righting moment curve approaches a minimum bur does not go negative.

The MCF hull consists of four main components as illustrated in Figure 3-40 along with corresponding structural weights:

(1) Columns

(2) Corner Pontoon Section

(3) Center Pontoon Section

(4) Cold Water Pipe support truss structure

A more detailed material takeoff weigh estimate is presented in Table 3-9. The "calculated weight" is directly derived from hull scantlings (dimensions and thicknesses). The "estimated weight" includes an allowance for mill tolerance and welding of about 5%. This is not a contingency, but an estimate based on past experience of the added weight. Table 3-9 also includes an estimate for the center of gravity of the hull which is used to derive stability and mass properties (for dynamic analysis).

Table 3-10 shows a takeoff of the outfitting weights which must be added to the structural weight to arrive at a total hull weight[4]. Appendix 3.3-8 includes further details regarding the hull weight estimate.

Hull general arrangements are illustrated in Figure 3-41 - Figure 3-43. Figure 3-41 shows outboard profile of the hull with remoras. The remoras are for illustration only and do not represent the current "truss spar" configuration of the remoras (see Section 3.3.2.1.1). Figure 3-42 and Figure 3-43 show sections through the column and pontoon respectively. These show the framing and compartmentation of these sections.

The ballast system is shown in Figure 3-44. The MCF ballast system is designed to be simple and failsafe. The ballast compartment is in the corner pontoon tank at the base of each column. A vertical caisson runs from the ballast tank to the top of the column. The tank is filed from an

[4] There are minor discrepancies in the weights between Table 3-9, Table 3-10, Figure 3-40 and Table 3-8. Table 3-8 represents the latest compilation.

external pump (not shown) through the water supply pipe. Ballast is discharged using a submersible pump which may be installed and removed from the caisson during operations. Since it is not expected that there will be continual ballasting required, these pumps may be stored on deck, or rented, as needed.

Figure 3-45 illustrates the vent and sounding systems which are provided for each tank. These consist of tubes running from the bottom of each tank (including the ballast tank) to the top of the columns where they are capped with flanges.

The topsides structural interface is shown in Figure 3-46. The deck is supported by a column at each corner which aligns with the corner of the deck truss frame (see Section 3.3.1.4). The hull interface consists of horizontal and vertical interstitial plating between the cells. These form effective girders for supporting the topsides foundation. The topsides may be welded to the supporting column, or grouted. Grouting was used for the Red Hawk spar/deck connection which was identical in concept to this. Grouting has the advantage that the tolerances on the deck framing and the hull interface do not have to be as precise as necessary for a welded connection.

The column to pontoon interface is shown in Figure 3-47. Gusset plates support the columns minimizing the local stresses that would arise normally in a column to pontoon connection.

Section 3.3.1.5.5 below discusses the global structural analysis of the hull.

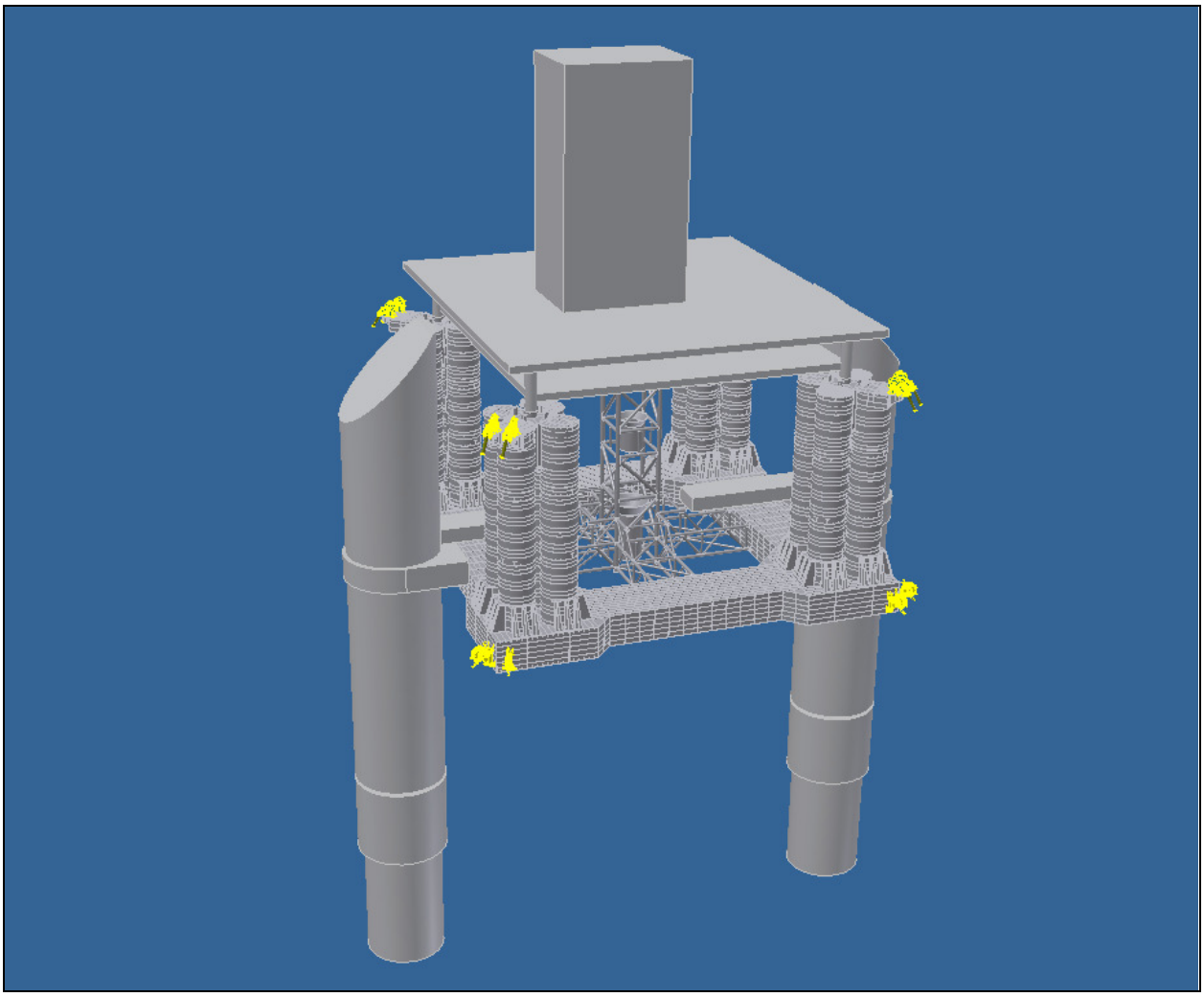


Figure 3-38. OTEC Multi-Column Floater

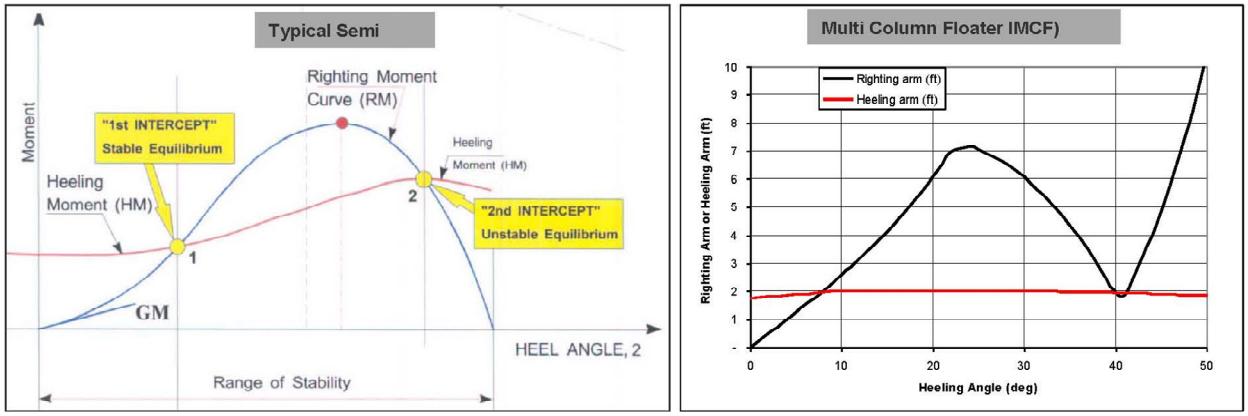


Figure 3-39. Stability Characteristics of the MCF

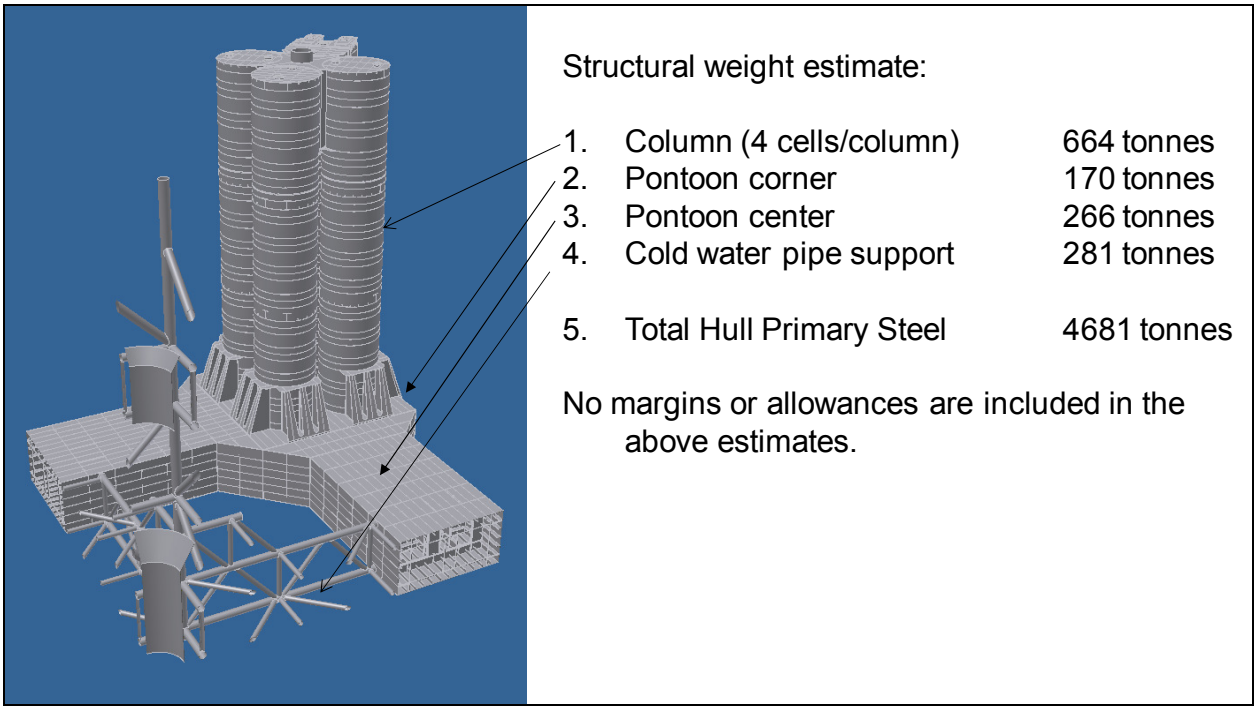


Figure 3-40. Quarter Section and Hull Weight

Table 3-9. Hull Structural Weight Material Takeoff

Weight Take-off Summary Description	Qty each	Calculated Weight (kg)	Estimated Weight (kg)	LCG (mm)	TCG (mm)	VCG (mm)
Pontoon		**1754412**	**1842133**	**0**	**0**	**2509**
Tank 10 Port	1	170087	178592	-25000	-24999	2496
Pontoon Port	1	268516	281942	-24999	0	2517
Tank 50 Port	1	170087	178592	-25000	24999	2496
Pontoon Forward	1	268516	281942	0	-25001	2517
Tank 10 Starboard	1	170087	178592	25000	-24999	2496
Pontoon Starboard	1	268516	281942	25001	0	2517
Tank 50 Starboard	1	170087	178592	25000	24999	2496
Pontoon Aft	1	268516	281942	0	24999	2517
Column Port Forward		**491463**	**516036**	**-25012**	**-25012**	**22171**
Cell 10 Port	1	123649	129831	-28269	-28269	22240
Cell 11 Port	1	122605	128735	-21750	-28250	22148
Cell 12 Port	1	122605	128735	-28250	-21750	22148
Cell 13 Port	1	122605	128735	-21750	-21750	22148
Column Starboard Forward		**491463**	**516036**	**25012**	**-24968**	**22171**
Cell 10 Starboard	1	123649	129831	28269	-28269	22240
Cell 11 Starboard	1	122605	128735	21750	-28250	22148
Cell 12 Starboard	1	122605	128735	28250	-21575	22148
Cell 13 Starboard	1	122605	128735	21750	-21750	22148
Column Port Aft		**491993**	**516592**	**-25008**	**25008**	**22175**
Cell 50 Port	1	122605	128735	-28250	21750	22148
Cell 51 Port	1	123134	129291	-21750	21750	22164
Cell 52 Port	1	123649	129831	-28269	28269	22240
Cell 53 Port	1	122605	128735	-21750	28248	22148
Column Starboard Aft		**491463**	**516036**	**25012**	**25011**	**22172**
Cell 50 Starboard	1	122605	128735	28250	21750	22148
Cell 51 Starboard	1	122605	128735	21750	21750	22149
Cell 52 Starboard	1	123649	129831	28269	28269	22240
Cell 53 Starboard	1	122605	128735	21750	28246	22148
Coldwater Pipe Support Truss		**281045**	**306900**	**2**	**0**	**8921**
Truss	1	212672	233939	3	0	8084
Guide	1	68373	72961	0	0	11604
MCF Hull Structure Weight		**4001839**	**4213734**	**-3**	**8**	**12611**

Table 3-10. Hull Outfitting Weight Material Takeoff

MCF - OTEC OUTFITTING							
Description	**Qty**	**Unit Wt.**	**Length**	**Wt**	**LCG**	**TCG**	**VCG**
		kg	m	kg	mm	mm	mm
Piping				**151157**			**24445.7**
Vent & Sounding				**36922**			**22591.7**
4" Vent / Sounding void 4	16	248.2		3972	0.0	0.0	31192.5
Striking plate	16	0.4		6	0.0	0.0	25629.0
Weld Neck Flange	16	7.3		117	0.0	0.0	36812.0
Blind Flange	16	7.5		120	0.0	0.0	36848.2
4" Vent / Sounding void 3	16	471.2		7539	0.0	0.0	26192.5
Striking plate	16	0.4		6	0.0	0.0	25629.0
Weld Neck Flange	16	7.3		117	0.0	0.0	36812.0
Blind Flange	16	7.5		120	0.0	0.0	36848.2
4" Vent / Sounding void 2	16	708.0		11328	0.0	0.0	20880.0
Striking plate	16	0.4		6	0.0	0.0	5004.0
Weld Neck Flange	16	7.3		117	0.0	0.0	36812.0
Blind Flange	16	7.5		120	0.0	0.0	36848.2
4" Vent / Sounding void 1A	16	819.5		13112	0.0	0.0	18380.0
Striking plate	16	0.4		6	0.0	0.0	4.0
Weld Neck Flange	16	7.3		117	0.0	0.0	36812.0
Blind Flange	16	7.5		120	0.0	0.0	36848.2
Ballast				**26438**			**22591.7**
Caisson	4	4726.0		18904	0.0	0.0	19243.0
Ballast pump	4	90.0		360	0.0	0.0	929.6
Air vent check valve	4	23.0		92	0.0	0.0	36.8
Check Valve	4	12.5		50	0.0	0.0	3828.0
Discharge string	4	1308.0		5232	0.0	0.0	20401.0
Ripouts (rupture disk)	20	90.0		1800	0.0	0.0	760.0
Marine systems				**87797**	0.0	0.0	**17868.4**
Seawater intake	1	9958.0		9958	0.0	0.0	20500.0
Overboard discharge	1	4361.0		4361	0.0	0.0	23300.0
scuppers and deck drain	4	2950.0		11800	0.0	0.0	35780.0
Skirt pile	2	30476.0		60952	0.0	0.0	26815.0
Utility air	4	40.0		160	0.0	0.0	36300.0
Hydraulic piping	1	566.0		566	0.0	0.0	36054.0
Electrical				**11248.0**	0.0	0.0	**20500.0**
cable & tray	4	2812.0		11248	0.0	0.0	20500.0
Mooring				**589534.8**	0.0	0.0	**15077.5**
Chain Jack & stopper	8	3129.0		25032	0.0	0.0	36000.0
Fairlead	8	18500.0		148000	0.0	0.0	3048.0
Utility winch	4	181.0		724	0.0	0.0	36050.0
Chain locker	8	37285.0		298280	0.0	0.0	15333.0
Chain inboard of fairlead	8	9982.0		79856	0.0	0.0	20250.0
Tail Chain	8	355.7		2845	0.0	0.0	20500.0
Power Unit	2	3628.7		7257	0.0	0.0	36260.0
Control House	2	7983.0		15966	0.0	0.0	37100.0
Deck fitting	16	610.0		9760	0.0	0.0	36200.0
Supply boat mooring padeye	2	907.0		1814	0.0	0.0	29000.0
Corrosion protection				**243863.0**	0.0	0.0	**13332.4**
Paint	16	4252.0		68032	0.0	0.0	30500.0
Anodes	1	175831.0		175831	0.0	0.0	6690.0
Structure Outfitting				**1001242.3**	0.0	0.0	**20764.3**
Hull markings	4	907.0		3628	0.0	0.0	24000.0
Ladders	16	1242.3		19876	0.0	0.0	20704.0
Manway top of column	32	144.4		4622	0.0	0.0	36177.0
Manways	96	270.6		25976	0.0	0.0	15767.0
Fnd Column	32	7810.0		249920	0.0	0.0	7065.0
Interstitial Decks	16	4990.0		79840	0.0	0.0	28500.0
Fnd Chain Jack & Stopper	8	12474.0		99792	0.0	0.0	36000.0
Fnd fairlead	8	19685.0		157480	0.0	0.0	3200.0
Fnd Topside	4	82282.0		329128	0.0	0.0	32940.0
Boat landing	1	30980.0		30980	0.0	0.0	23746.0
Outfitting Weight Total				**1997045.33**	**0.0**	**0.0**	**18455.2**

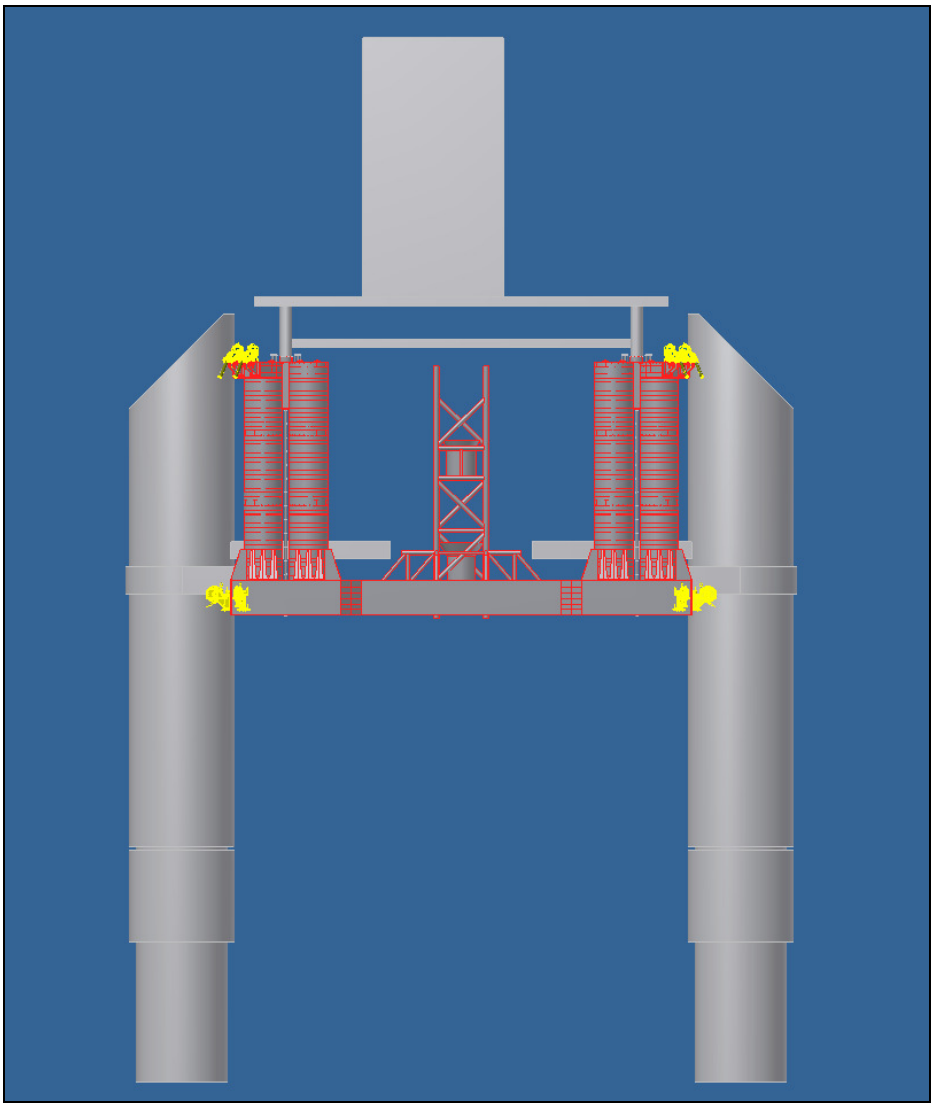


Figure 3-41. Elevation – Outboard Profile

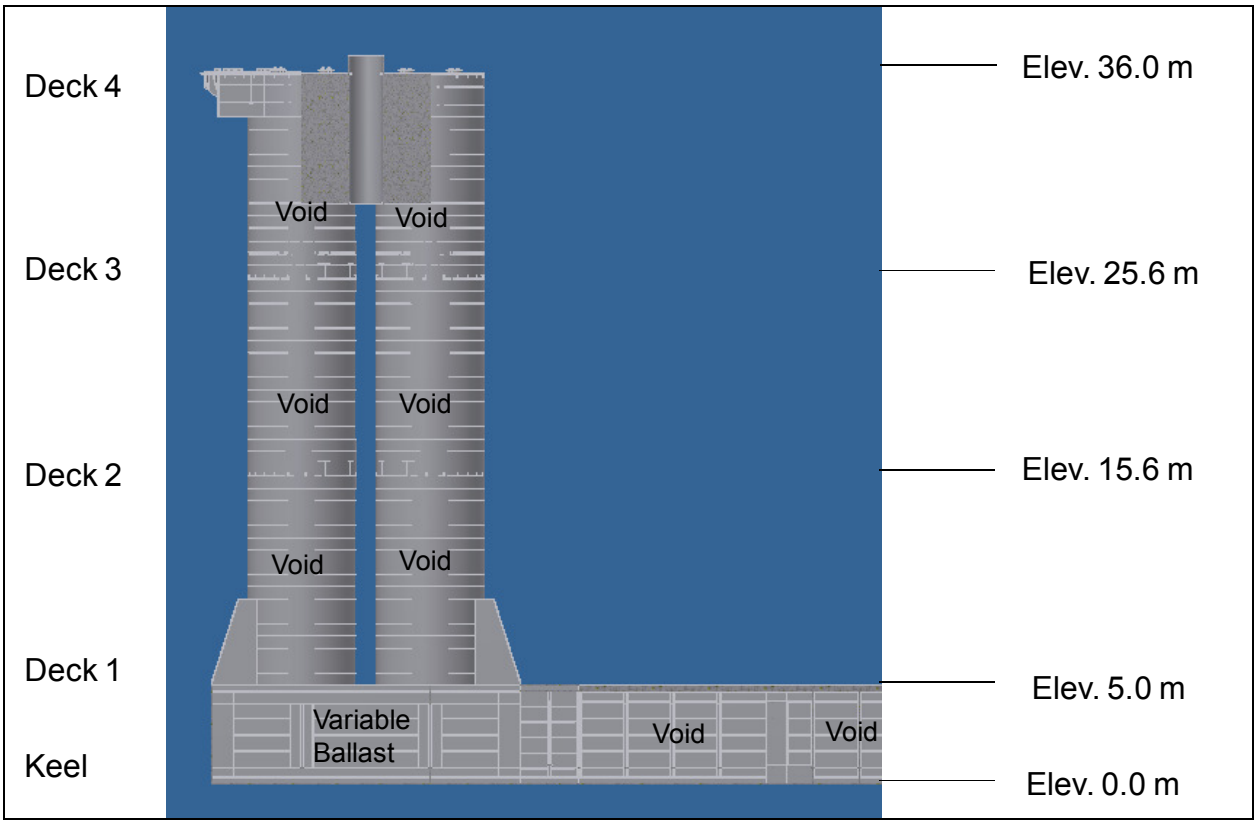


Figure 3-42. Section Through Corner

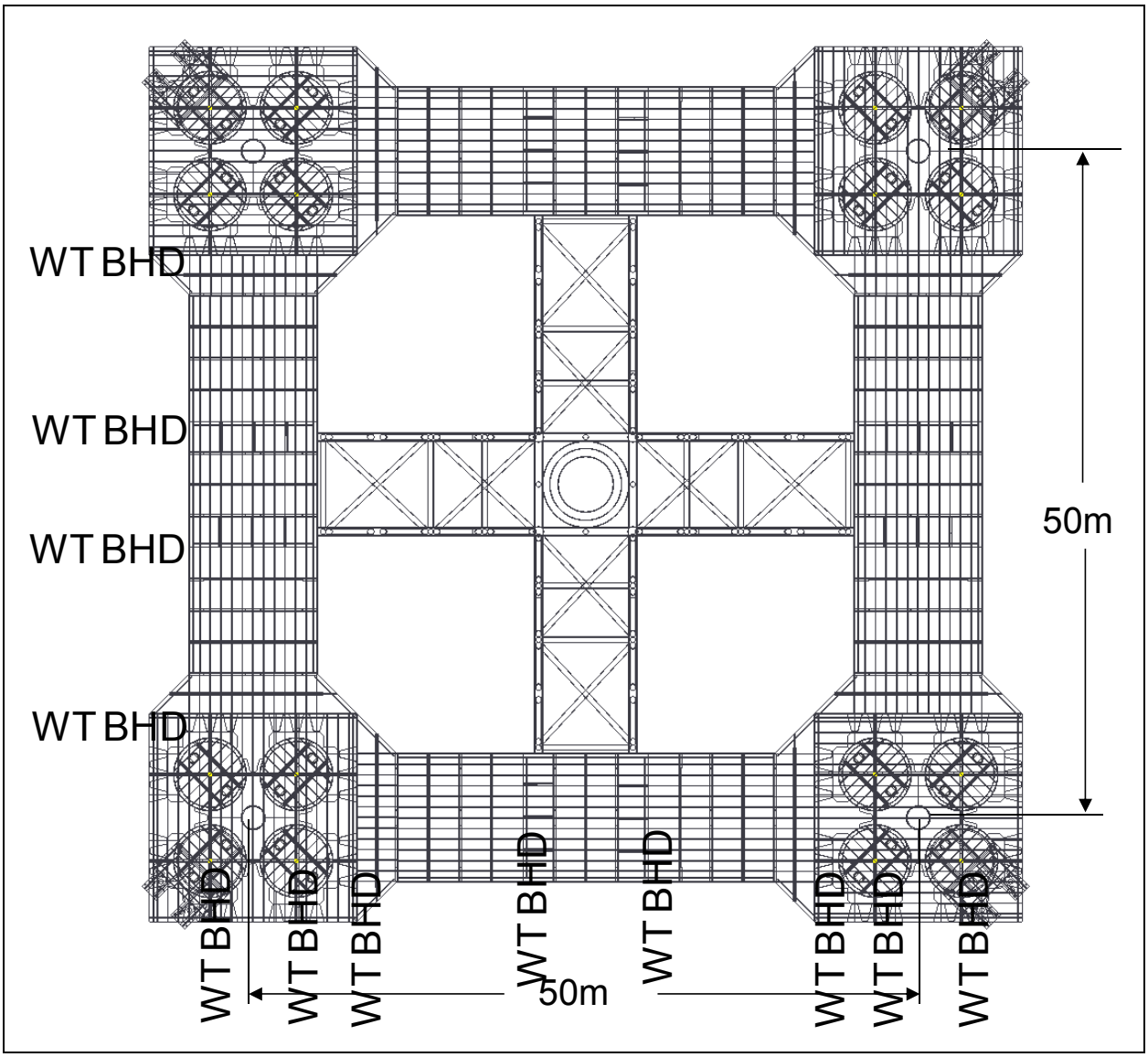


Figure 3-43. Section Through Pontoon

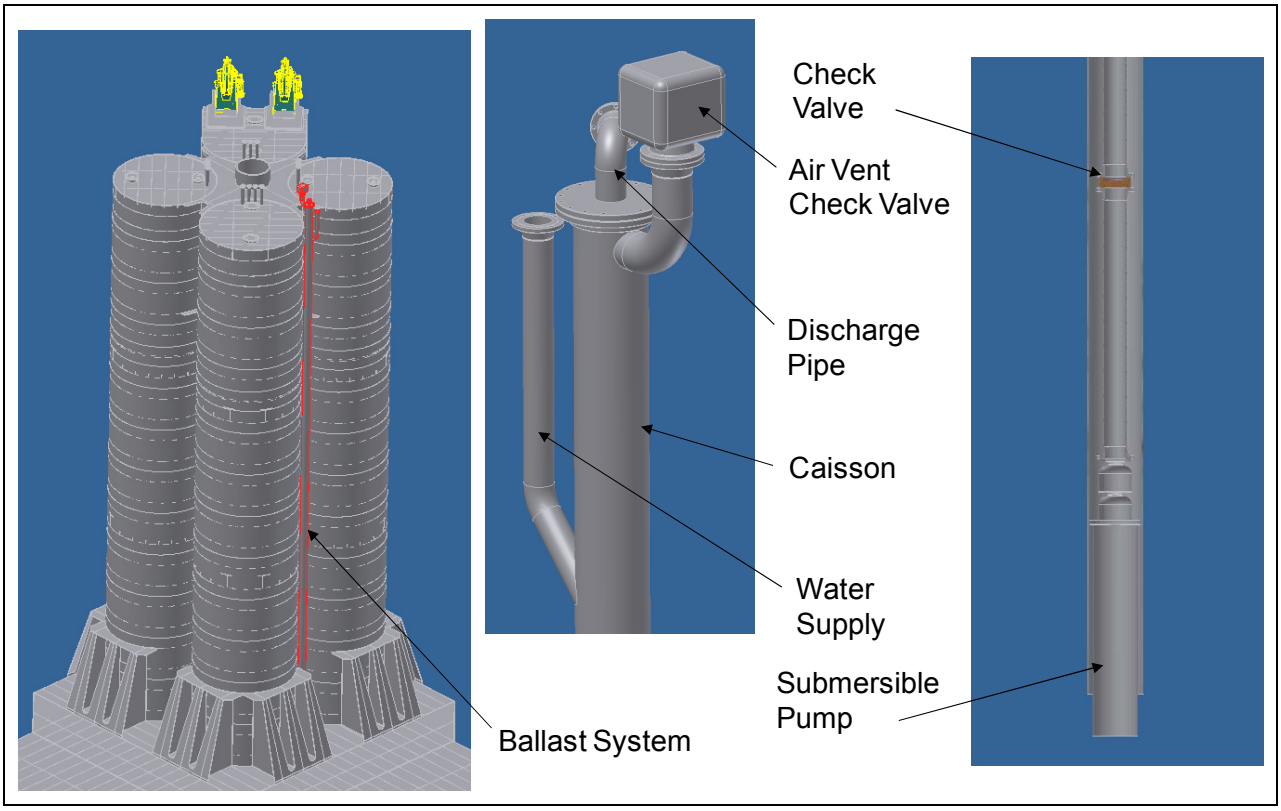


Figure 3-44. Marine System - Ballast

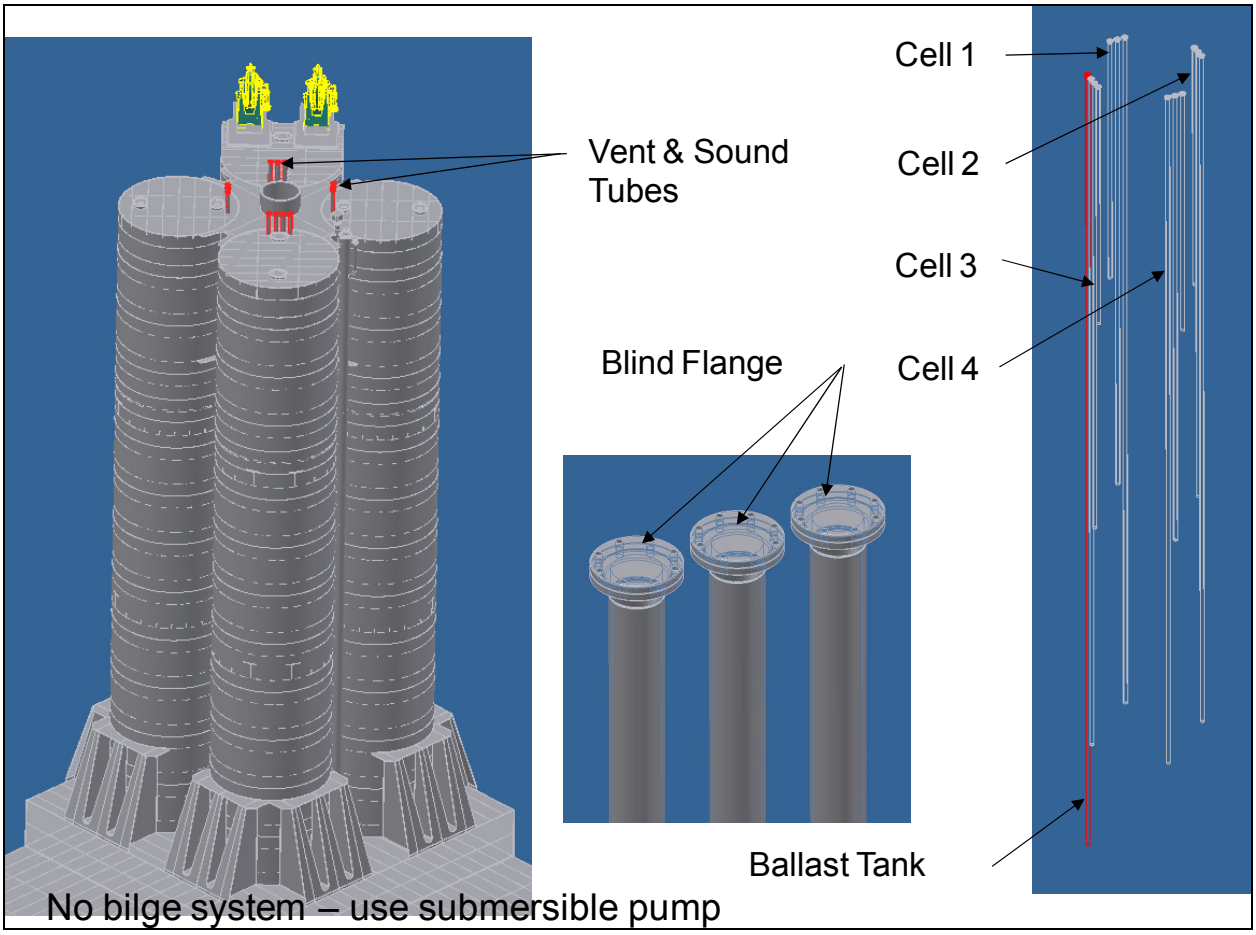


Figure 3-45. Marine System – Vent and Sounding

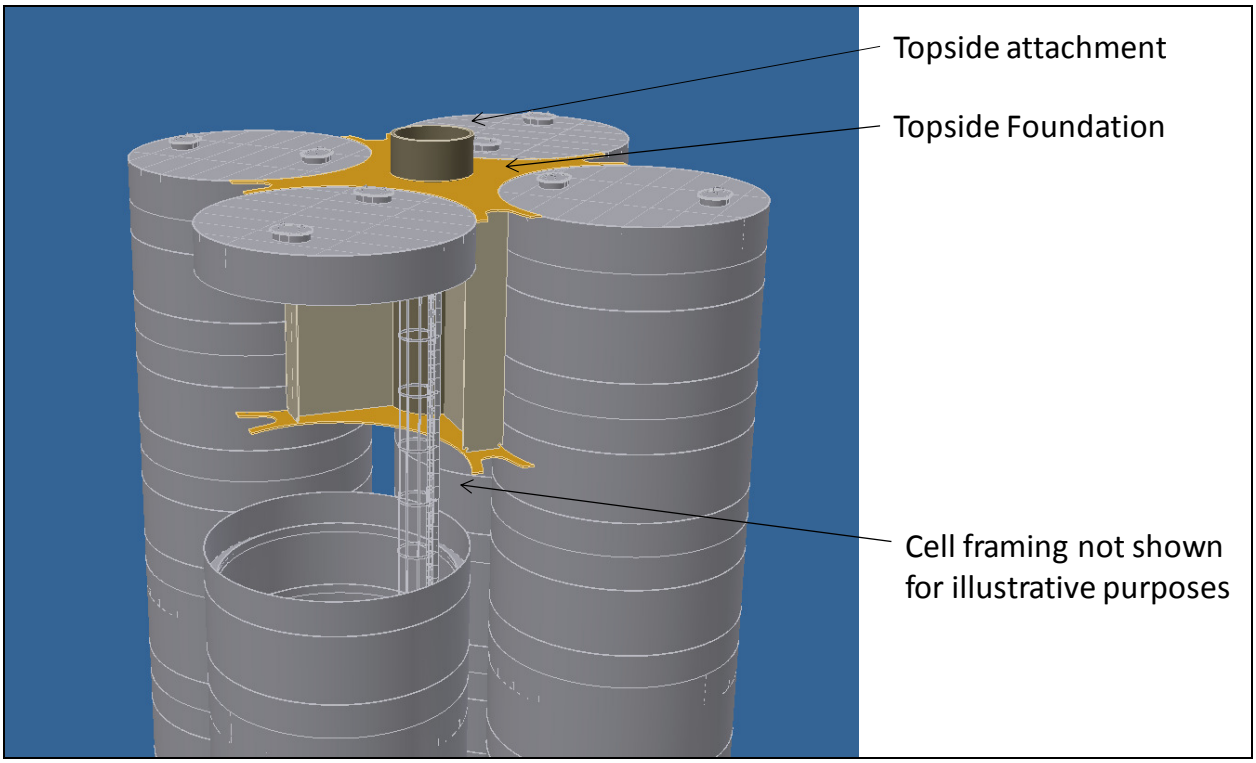


Figure 3-46. Topside Pontoon Interface

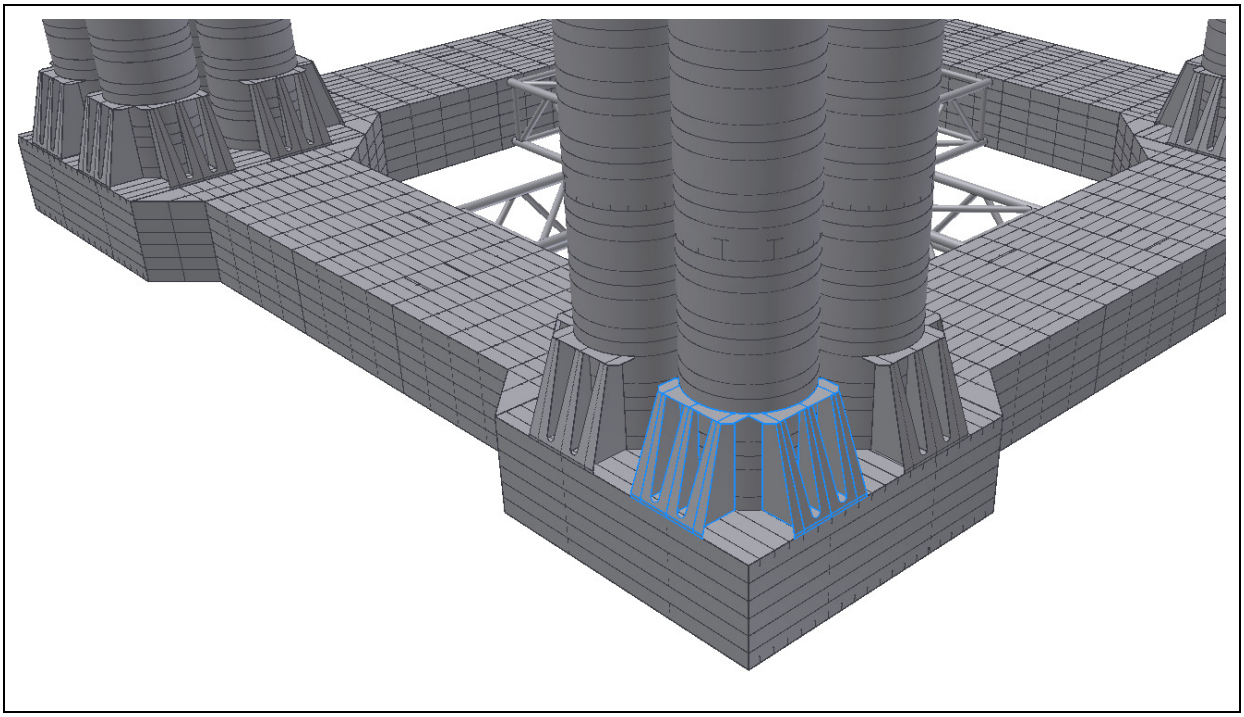


Figure 3-47. Cell to Pontoon Attachment

3.3.1.5.2 Global Performance Analysis

Global performance analysis was performed during the hull sizing exercise to evaluate platform motions and mooring loads under operational and extreme conditions in order to qualify it for OTEC operations[10], see Appendix 3.3-9. Further analysis was conducted by HWD during the optimization of the mooring system, see Section 3.3.1.8.

Table 3-11 shows the natural period of the platform in the fabrication and full production stages. The effect of the remoras on the natural periods is remarkable, notice the reduction in both the heave and pitch periods. The roll period is not affected because the remoras are only in the pitch direction.

Table 3-11. Platform Natural Periods

Natural Periods		Pipe Fabrication	Production
Motion	**Unit**	**Hull**	**Hull**
Surge	sec	112.0	115.5
Sway	sec	124.0	115.5
Heave	sec	25.0	20.0
Roll	sec	27.7	26.7
Pitch	sec	27.0	18.8
Yaw	sec	72.7	51.3

The motions were computed for the extreme criteria in Table 3-4. Figure 3-48 through Figure 3-50 summarize the results for the three stages. "Max Heel" refers to the combination of static and dynamic pitch/roll motions, or total inclination including dynamic effects.

The results are presented for both the intact and missing mooring line cases. The "missing" mooring line case is required by ABS to confirm the reserve strength of the mooring system. The heave and heel responses for the full production case are larger than the pilot responses because of the increased environment: 100-yr vs. 25-yr return period. The smaller offset for the full production case reflects an upgraded mooring system.

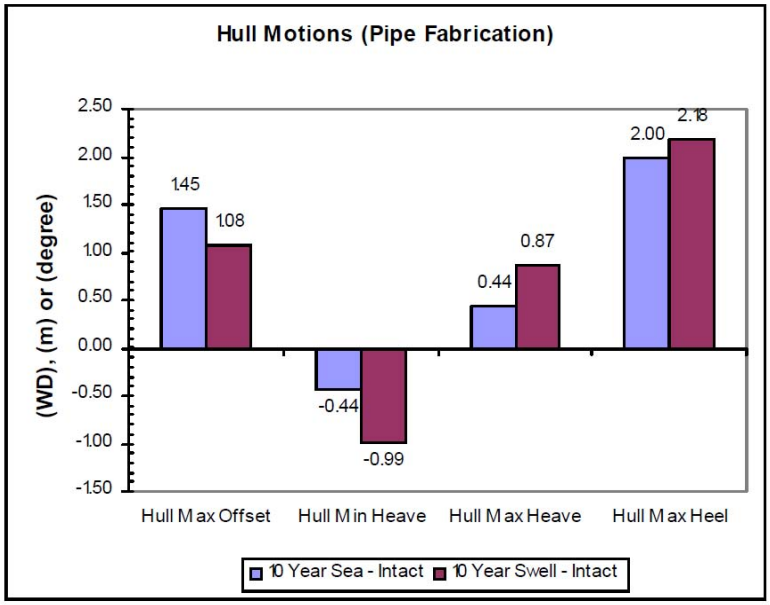


Figure 3-48. Hull Motions Stage 1 – Pipe Fabrication

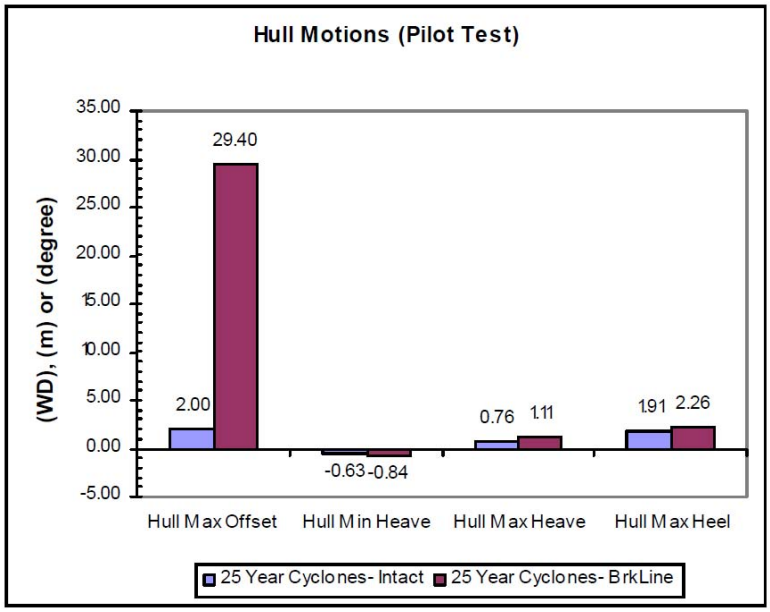


Figure 3-49. Hull Motions Stage 2 – Pilot Tests

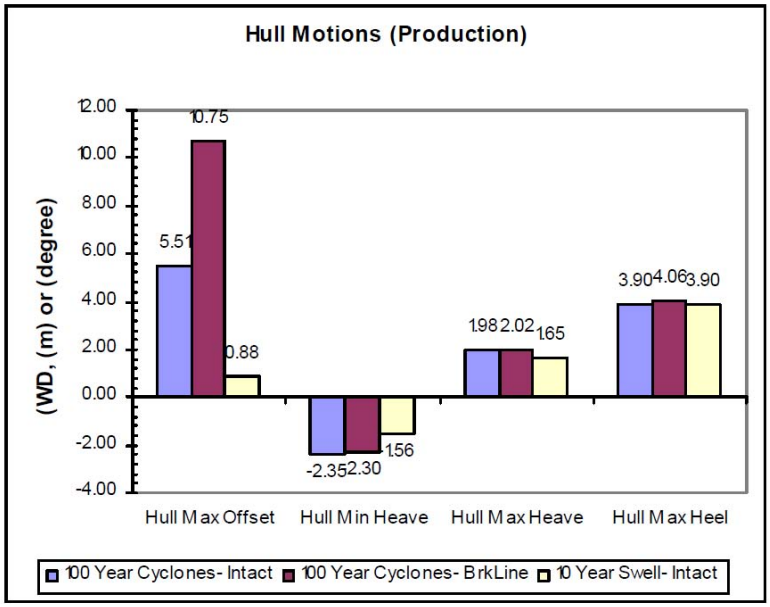


Figure 3-50. Hull Motions Stage 3 – Full Production

3.3.1.5.3 Global Structural Analysis

A global structural analysis was performed for the entire platform structure to confirm the design of the major deck and hull structural components and member sizes. The analysis was performed by using two structural models. The first model focused on the design and analysis of the deck truss structural members, including the support frame for the cold water pipe. The hull structure was included in the model as equivalent beam elements. The second model focused on the global hull structure with stiffened plated structure modeled as finite-elements. The deck and truss frame structures were included as equivalent beam elements. Both models were calibrated to the correct mass and stiffness of the platform structure, and analyzed for all the governing loading conditions for the various stages of platform operation. The Remora units were included in the structural models, and the loads were investigated by providing adequate support reinforcements at the connecting points. The following sections present the global analysis procedure, and discuss the code checking of the structural elements to satisfy the prescribed standard offshore industry requirements of API and ABS.

The deck structure is governed by the loading conditions of the CWP fabrication phase (maximum payload) and the 10 MW full production phase of the platform (maximum extreme storm load). The deck structure was designed based on both static and dynamic analysis of the loading conditions considered. The CWP supporting structure is designed for strength and stiffness requirements. The unity checks of the preliminary member sizing are reported in this document.

3.3.1.5.4 Structural Computer Models and Design Basis

The OTEC platform configuration is based on the principal general arrangements drawings presented in previous sections. A separate computer model was developed for each design phase. Figure 3-51 shows the structural model for static and dynamic analysis during the Stage 1 CWP fabrication phase along with the fabrication tower and apparatus. The structural software called MicroSAS was used. Figure 3-51 shows the isometric plot of the model. All structural members were designed using 50 kilo-pound per square inch (ksi) grade steel. Pinned boundary conditions are assumed at the hull. All the connections between hull pontoons and the CWP support frame are assumed to be rigid.

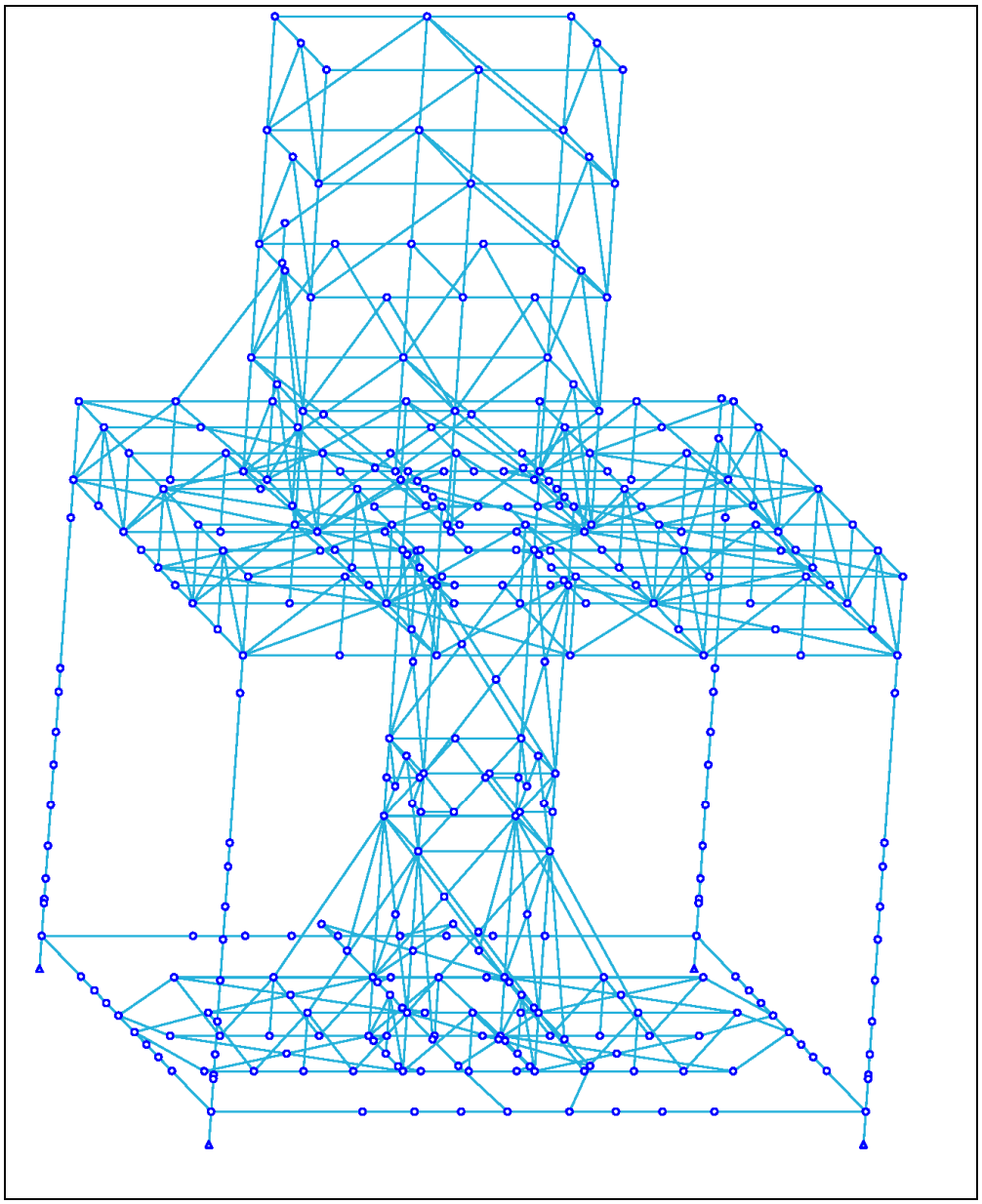


Figure 3-51. MicroSAS Model for Static Analysis during Fabrication Phase

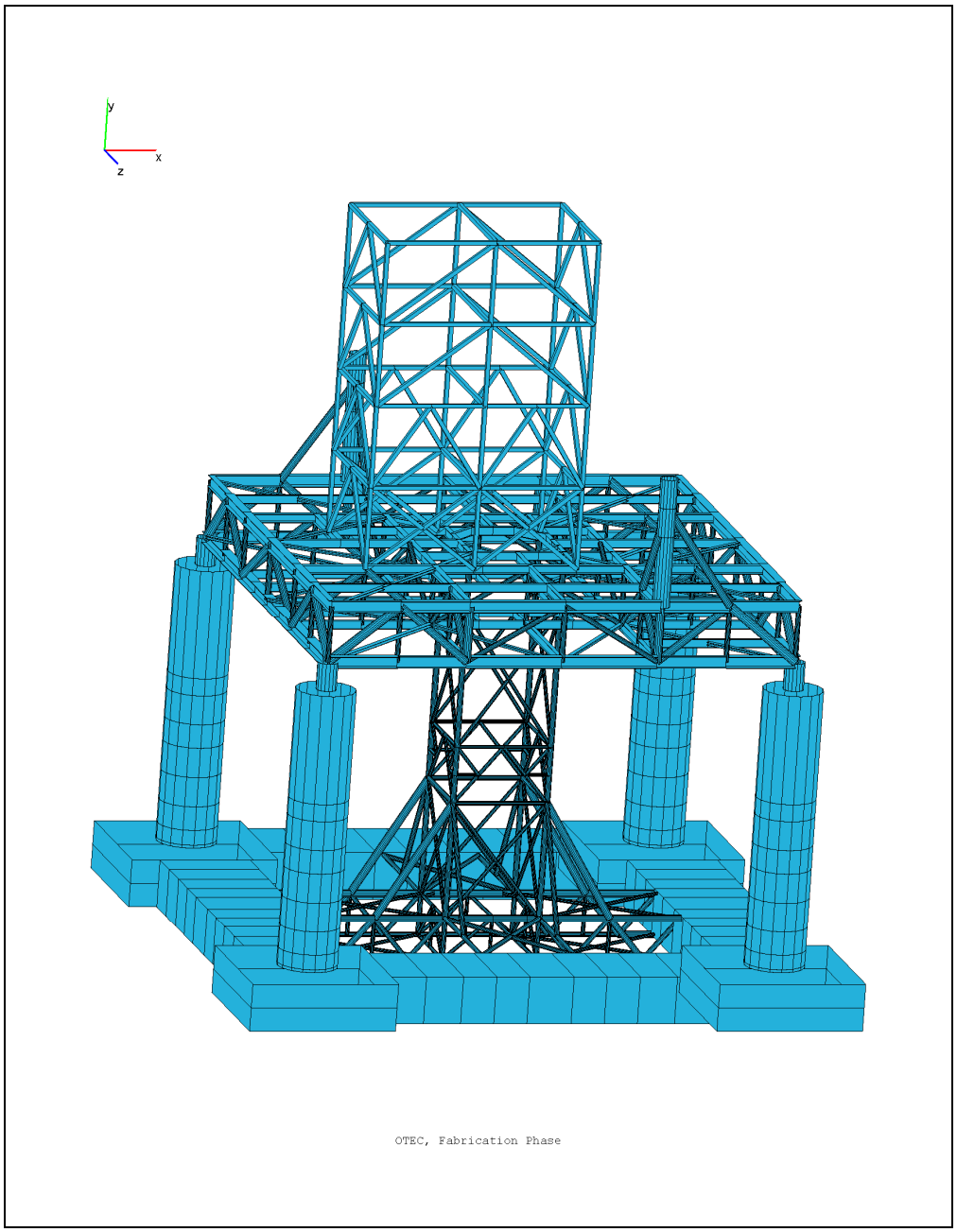


Figure 3-52. Isometric View during Fabrication Phase

Figure 3-51and Figure 3-53 are the structural models for the static and dynamic analysis during full 10 MW production phase respectively. The Remora units were modeled as equivalent beam elements. All the connections with Remoras at the deck and pontoon levels were also assumed to be rigid. For the dynamic analysis during full production phase the Remoras are not included in the model because the vertical force at the deck connections is negligible. Hence only the appropriate lateral loads from Remoras were applied at the deck connections. Figure 3-54 shows

the isometric plot of the structural model during full production phase for static and dynamic analysis.

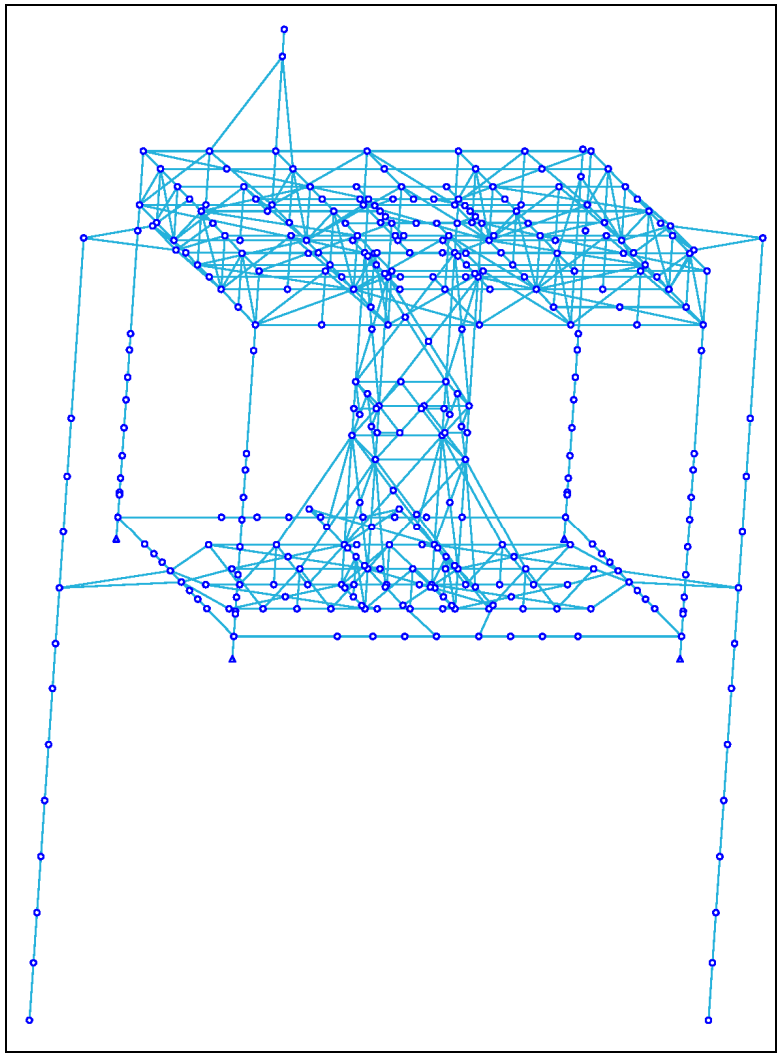


Figure 3-53. MicroSAS Model for Dynamic Analysis during 10 MW Production Phase

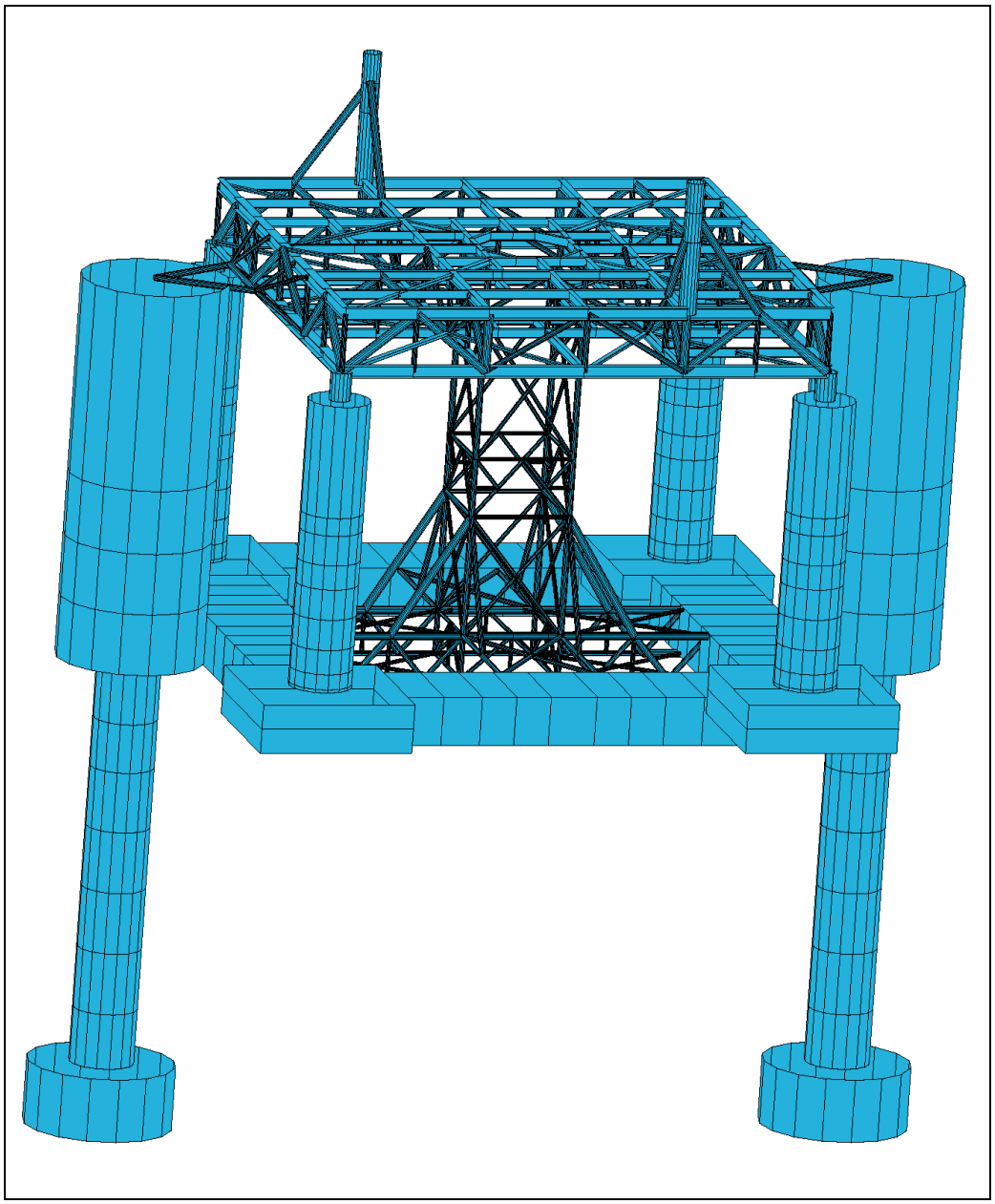


Figure 3-54. Isometric View during 10 MW Full Production Phase

Summaries of the load conditions and design criteria for static and dynamic analysis are listed in Table 3-12 and Table 3-13.

Table 3-12. Load Conditions and Design Criteria for Static Analysis

Design Criteria - Static Analysis		Fabrication Phase	Full Production Phase
Load	**Description**	**Weight (mt)**	**Weight (mt)**
Fabrication Tower Loads	Steel and Equipments Gripper Structure and pads	571.71 309.30	-
Topsides Equipment	Tower Loads All other Equipments	881.01 1108.00	1688.00
Topsides Structure	Deck CWP Structure Total * 1.67	1014.18 285.09 2164.00	1014.18 285.09 2164.00
Hull	Structure and Outfittings	6481.00	6481.00
CWP Loads	including mooring loads	755.00	1159.00
Ballast		8001.34	7880.41
Remora A & B	Each Remora	-	5318.00
Hydro-Static Loads		19041.96	33525.71
Allowable Stress	No increase for static	1.00	1.00
Steel Material	Yield Strength	50 Ksi	50 Ksi

The following are the controlling design conditions and sources for the dynamic analysis of the deck structure:

- For global pry-squeeze wave controlled conditions, wave period of 9.5 seconds with design wave height of 25.55 m (83.84 ft) were used.
- Global lateral acceleration values of 0.09g and 0.19g for fabrication and full production phases are from Global Performance Report by Horton Wison Deepwater.
- Gripper & Guide loads and the required CWP support structure stiffness if 10^8 N/m are from Gripper and Platform Interfacing Report by Makai Ocean Engineering.
- Remora loads at deck support are from Global hull Analysis by Houston Offshore Engineering.

Table 3-13. Load Conditions and Design Criteria for Dynamic Analysis

Design Criteria - Static Analysis		Fabrication Phase	Full Production Phase
Load	**Description**	**Weight (mT)**	**Weight (mT)**
Topsides Equipment	Vertical Acceleration Lateral Acceleration	0.06g 0.09g	0.08g 0.19g
Topsides Structure	Vertical Acceleration Lateral Acceleration	0.06g 0.09g	0.08g 0.19g
Hull	Structure and Outfittings	6481.00	6481.00
CWP Loads	including mooring loads	755.00	1159.00
Ballast		8001.34	7880.00
Pry/Squeeze Loads	0 Deg heading on each columns 45 Deg heading on diagonal columns	2109.21 2585.48	2109.21 2585.48
Wind Loads		10-yr sea 15.7 m/sec	100-yr cyclone 33.8 m/sec
Gripper/Guide Loads	Upper Gripper Vertical Loads Upper Gripper Lateral Loads Lower Gripper Vertical Loads Upper Guide Vertical Loads Upper Guide Lateral Loads Lower Guide Vertical Loads Lower Guide Lateral Loads	314.59 21.27 314.59 31.41 303.78 31.41 387.49	-
Remora Deck Support	From Global Hull Analysis Max in East/West (in kN) Max in North/South (in kN)	-	 4825.00 4063.00
Allowable Stress Ratio		1.33	1.67

3.3.1.5.4.1 Load Definitions

3.3.1.5.4.1.1 Tower Loads

The CWP fabrication tower was modeled using 16" x 16" square tubing. The total weight of steel and fabrication equipment from Global Weight Report is 571.71 mt, and the weight of gripper structure and its pads are 309.30 mt. Respective vertical and lateral accelerations were applied in the dynamic analysis. Once the CWP fabrication phase is complete, the fabrication tower will be removed.

3.3.1.5.4.1.2 Topsides Equipment Loads

The loads from topsides equipment were uniformly distributed on both upper and lower decks. The total applied weights of equipment during fabrication phase is 1108 mt and the equipment during the full production phase 1688 mt. Respective vertical and lateral accelerations were applied in dynamic analysis.

3.3.1.5.4.1.3 Gravity Loads

The deck and hull steel weights are calibrated to match the weight and loads as reported in the Global Weight Report by using the appropriate factors in the load combinations. The factors are 1.667 and 1.437 for the computer modeled weight of the deck and the hull, respectively. Respective vertical and lateral accelerations were applied in the dynamic analysis.

3.3.1.5.4.1.4 Cold Water Pipe (CWP), Mooring and Ballast Loads

The loads from the Cold Water Pipe, mooring loads and ballast loads were also considered for the static and dynamic analysis of both fabrication and full production phases.

3.3.1.5.4.1.5 Environmental Loads

The design wind speed during fabrication phase for 10 year wave condition is 15.7 m/sec (1-hr at 33 m) and design speed during full production phase for 100 year cyclone is 33.8 m/sec (1-hr at 33 m). Note the fabrication tower is removed during full 10 MW production phase.

3.3.1.5.4.1.6 Pry/Squeeze Loads

The design wave approach was used to compute the dominant hydrodynamic load responses on the hull structure. Two design waves determined to be the governing wave load conditions were applied to the structure. The design wave of 9.5 second period and 25.55-m (83.84-ft) height wave produce a pry/squeeze loads of 2,109.21 mt (4,650 kips) to be applied on each hull column for the 0° and 90° wave headings, and 2,584.48 mt (5,700 kips) on the diagonally-opposite columns for the 45° wave heading.

3.3.1.5.4.1.7 Gripper/Guide Loads

The total vertical and lateral loads at each gripper and guides was obtained from Makai Ocean Engineering report and summarized in Table 3-14. From the fabrication sequence, three possible scenarios can happen; first the total weight of Cold Water Pipe can be engaged by upper gripper, and two guides, second the weight is carried by both grippers and by both guides, and finally the total weight is carried by lower gripper and two guides. The second scenario is not critical and hence it was not considered in the analysis.

Table 3-14. Gripper and Guide Loads

	Vertical Load (kN)		Lateral Load (kN)	
Component	**Static**	**Dynamic (+/-)**	**Static**	**Dynamic (+/-)**
Upper Gripper	2,912	173	39	170
Lower Gripper	2,912	173	-	-
Upper Guide	291	17	566	2,413
Lower Guide	291	17	722	3,078

3.3.1.5.4.1.8 Remora Loads

The loads from the Remoras through connections to the deck are obtained from the Global Hull Analysis, and these loads are summarized in Table 3-15.

Table 3-15. Remora Loads at Deck Connection

Remora Connections				Corresponding max. Reactions		
Number	Load case	phase (°)	node nr.	Fx (kN)	Fy (kN)	Fz (kN)
1	4	175	Deck	-4825	-4057	0
2	2	175	Deck	-1889	1016	0
	4	0	Deck	1852	1416	0
3	4	-175	Deck	4587	4063	0
4	2	5	Deck	-1762	701	0
	4	0	Deck	84	-1890	0

3.3.1.5.4.2 Load Combinations

Table 3-16 shows all the basic loads and combinations defined in the structural analysis including static, wind, pry/squeeze, inertia, and gripper loads for the fabrication phase. An example load combination for A100 – A800 are shown in detail in Table 3-16. For inertia loads, vertical acceleration of 0.06g and lateral acceleration of 0.09g is applied for tower loads, live loads and dead loads in all the load combinations from A100 series to H100 series in all eight wave directions. Similarly hull dead load, Cold Water Pipe loads and ballast loads are included in each load combination. Wind load is also included in all load combinations with appropriate wind direction. A100 to D800 are Pry load combinations and E100 to H800 are squeezing load combinations. Gripper and guide loads are included in the combinations with appropriate directions.

Table 3-17 shows the load combinations that were performed in the MicroSAS structural analysis for full production phase. Remora loads at deck connections were obtained from Global hull Analysis. Possible load combinations were developed with maximum load at one deck connection and its corresponding loads at other connections. All these load cases were combined further with Pry/Squeeze loads for each heading. Remora loads highlighted in red at the maximum (+/-) forces at the deck connection for that particular wave heading. For example, A100 load combination for 0° wave heading and pry loads have maximum remora loads (+/-) at all the deck connections in both lateral directions.

Table 3-16. Basic Loads and load Combination for Fabrication

Basic Loads	Weight (mt)	Load Combinations w/ Pry Loads, Case1 of Gripper Loads								Pry + Case2	Pry + Case3	Pry + Case4	SQZ + Case1	SQZ + Case2	SQZ + Case3	SQZ + Case4
		A100	A200	A300	A400	A500	A600	A700	A800	B100 - B800	C100 - C800	D100 - D800	E100 - E800	F100 - F800	G100 - G800	H100 - H800
Tower_LdsX	881.00	0.09	0.064		-0.064	-0.09	-0.064		0.064							
Tower_LdsY	881.00	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Tower_LdsZ	881.00		-0.064	-0.09	-0.064		0.064	0.09	0.064							
LIVE_LDSX	1108.00	0.09	0.064		-0.064	-0.09	-0.064		0.064							
LIVE_LDSY	1108.00	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.00	1.00	1.00	1.00	1.00	1.00	1.00
LIVE_LDSZ	1108.00		-0.064	-0.09	-0.064		0.064	0.09	0.064							
DEAD_X	2164.00	0.09	0.064		-0.064	-0.09	-0.064		0.064							
DEAD_Y	2164.00	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.00	1.00	1.00	1.00	1.00	1.00	1.00
DEAD_Z	2164.00		-0.064	-0.09	-0.064		0.064	0.09	0.064							
HULL_Y	6481.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
CWP_LDS	755.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BALLAST_LDS	8001.34	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Wind Loads	@ 15.7 m/sec	0°	45°	90°	135°	180°	225°	270°	315°	0° - 315°	0° - 315°	0° - 315°	0° - 315°	0° - 315°	0° - 315°	0° - 315°
PRY_0	0.00	1.00				1.00										
PRY_45	0.00		1.00				1.00			1.00	1.00	1.00				
PRY_90	0.00			1.00				1.00								
PRY_135	0.00				1.00				1.00							
SQZ_0	0.00															
SQZ_45	0.00															
SQZ_90	0.00												1.00	1.00	1.00	1.00
SQZ_135	0.00															
UP_GRP_X	21.27	1.00	0.707		-0.707	-1.00	-0.707		0.707							
UP_GRP_Y	314.58	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00		1.00		1.00	
UP_GRP_Z	21.27		-0.707	-1.00	-0.707		0.707	1.00	0.707							
LO_GRP_Y	314.58									1.00		1.00		1.00		1.00
UP_GUD_X	303.78	1.00	0.707		-0.707	-1.00	-0.707		0.707							
UP_GUD_Y	314.58	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
UP_GUD_Z	303.78		-0.707	-1.00	-0.707		0.707	1.00	0.707							
LO_GUD_X	387.49	1.00	0.707		-0.707	-1.00	-0.707		0.707							
LO_GUD_Y	314.58	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	-1.00	-1.00	1.00	1.00	-1.00	-1.00
LO_GUD_Z	387.49		-0.707	-1.00	-0.707		0.707	1.00	0.707							

Table 3-17. Basic Loads and load Combination for Full Production Phase

Basic Loads	Weight (Mt)	Pry+Remora @ 0° Heading		Pry + Remora @ 45° Heading										Pry+Rem90°	Sqz+Rem0°	Sqz+Rem45°	Sqz+Rem90°
		A100	A101	B100	B101	B102	B103	B104	B105	B106	B107	B108	B109	C100 - C107	D100 - D101	E100 - E109	F100 - F107
LIVE_LDSX	1108.00	0.19	0.19	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134		0.19	0.134	0.19
LIVE_LDSY	1108.00	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
LIVE_LDSZ	1108.00			-0.134	-0.134	-0.134	-0.134	-0.134	-0.134	-0.134	-0.134	-0.134	-0.134	-0.19		0.134	
DEAD_X	2164.00	0.19	0.19	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134		0.19	0.134	0.19
DEAD_Y	2164.00	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
DEAD_Z	2164.00			-0.134	-0.134	-0.134	-0.134	-0.134	-0.134	-0.134	-0.134	-0.134	-0.134	-0.19		0.134	
HULL_Y	6481.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
CWP_LDS	755.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ballast_LDS	8001.34	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Wind Loads	@33.8 m/sec	0°	0°	45°	45°	45°	45°	45°	45°	45°	45°	45°	45°	90°	0°	45°	90°
PRY_0	0.00	1.00	1.00														
PRY_45	0.00			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00				
PRY_90	0.00													1.00			
SQZ_0	0.00														1.00		
SQZ_45	0.00															1.00	
SQZ_90	0.00																1.00
NW_Deck_X	varies	178.34	-206.020	464.32	-492.00	434.40	-462.14	462.75	-490.48	-485.28	457.55	456.53	-484.16	varies	varies	varies	varies
NW_Deck_Z	varies	-85.55	109.31	-389.94	413.70	-364.85	388.61	-388.61	412.37	407.99	-384.33	-383.41	407.17	varies	varies	varies	varies
SW_Deck_X	varies	190.08	-192.620	25.59	-28.14	27.59	-30.15	24.58	-27.12	-25.90	23.35	27.02	-29.57	varies	varies	varies	varies
SW_Deck_Z	varies	90.55	-103.60	-143.98	130.93	-132.16	119.10	-144.36	131.34	130.63	-146.68	-140.11	127.06	varies	varies	varies	varies
SE_Deck_X	varies	-166.83	169.580	-460.81	463.56	-411.05	413.70	-464.68	467.44	467.71	-464.98	-442.66	445.41	varies	varies	varies	varies
SE_Deck_Z	varies	65.87	-91.67	384.53	-410.33	340.89	-366.69	388.00	-413.80	-414.31	388.41	368.53	-394.32	varies	varies	varies	varies
NE_Deck_X	varies	-178.04	156.630	8.87	-30.29	8.67	-30.08	8.57	-29.98	-29.47	8.06	9.04	-30.45	varies	varies	varies	varies
NE_Deck_Z	varies	-70.46	86.470	191.71	-175.70	173.66	-157.65	192.73	-176.72	-176.41	192.42	185.38	-169.37	varies	varies	varies	varies

3.3.1.5.4.3 Global Deck Structural Analysis Results for CWP Fabrication Phase

The global static and dynamic structural analysis of the deck model is performed in MicroSAS using the load combinations defined in Table 3-16. A total of 64 load cases were computed for dynamic analysis during CWP Fabrication Phase. The structure was checked for strength as per API RP-2A for both girder/beams and tubular members.

Figure 3-55 shows the members with the higher stress ratios (greater than 0.8). Localized high stresses can be resolved in more detailed design. Figure 3-56 shows most of the upper deck members which have high stress ratios at the boundary of the fabrication tower due to shear loads. Figure 3-57 shows the lower deck members with stress ratios greater than 0.8. The beam sections with the stress ratios greater than 1.0 is caused by out of plane moment. Figure 3-58 shows the CWP supporting structure members with stress ratios greater than 0.8 and most of the high stress members are located at pontoon connections and can be resolved in the detailed design phase.

Maximum relative deflections of the CWP fabrication tower with respect to the upper gripper structure have been calibrated. The maximum relative vertical deflection is 1.02”, maximum lateral deflection in N/S direction is 2.30”, and maximum lateral deflection in E/W direction is 1.61”. If only static loads are considered then the maximum relative vertical deflection is 0.571”, maximum lateral deflection in N/S direction is 0.361” and maximum lateral deflection in E/W direction is 0.086”.

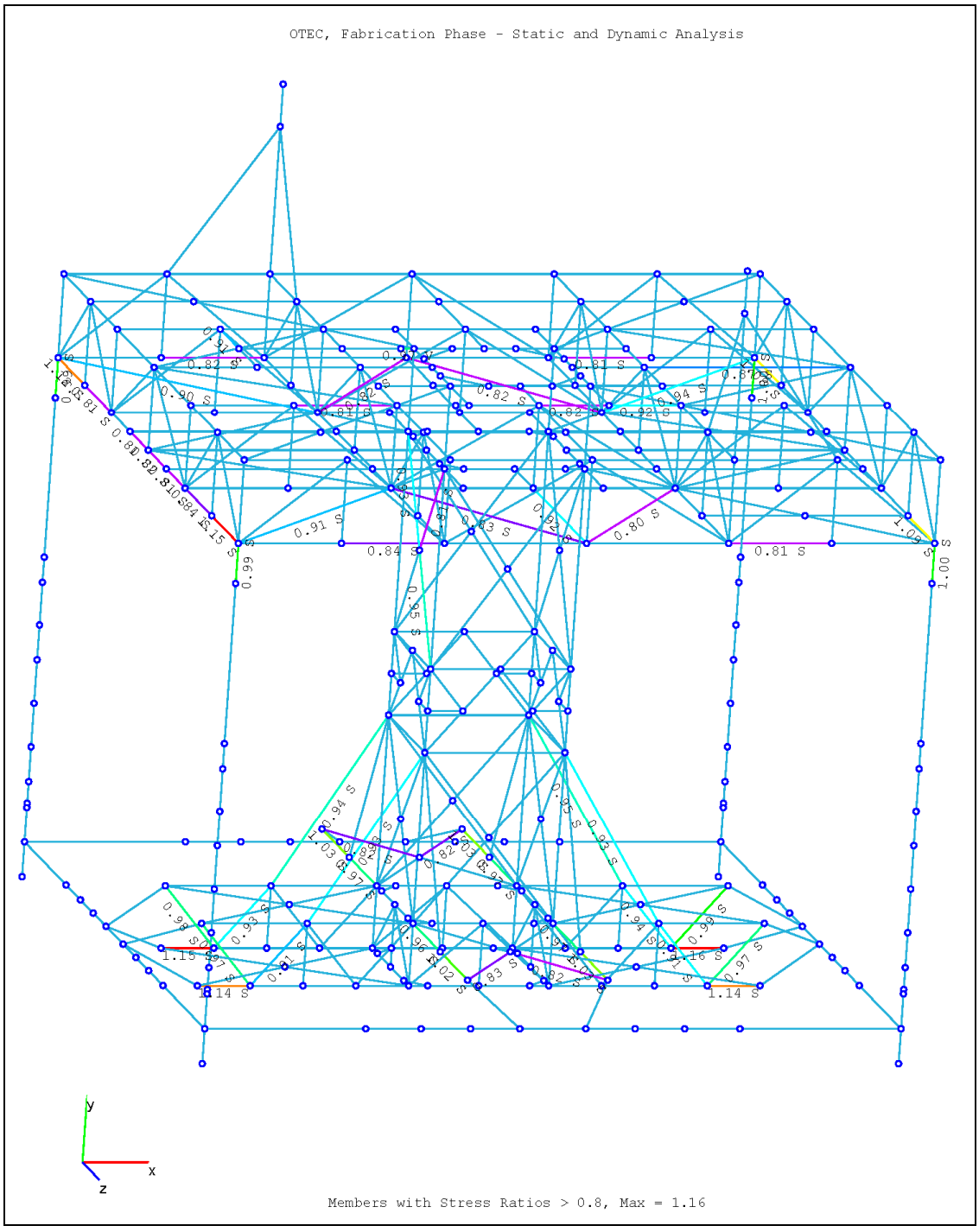


Figure 3-55. Members with Stress Ratios > 0.80 (Max: 1.16) – Fabrication Phase

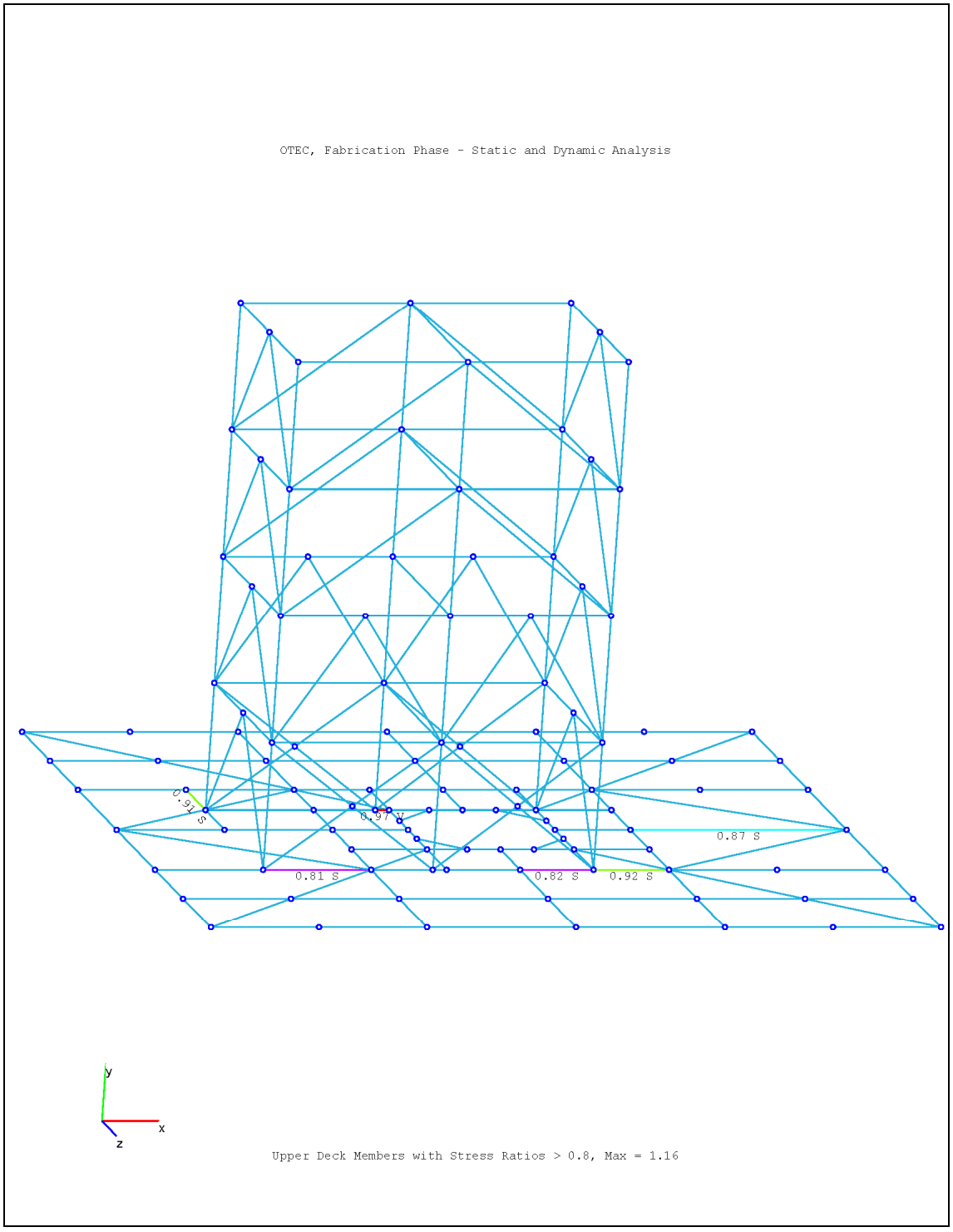


Figure 3-56. Upper Deck Members with Stress Ratios > 0.80 – Fabrication Phase

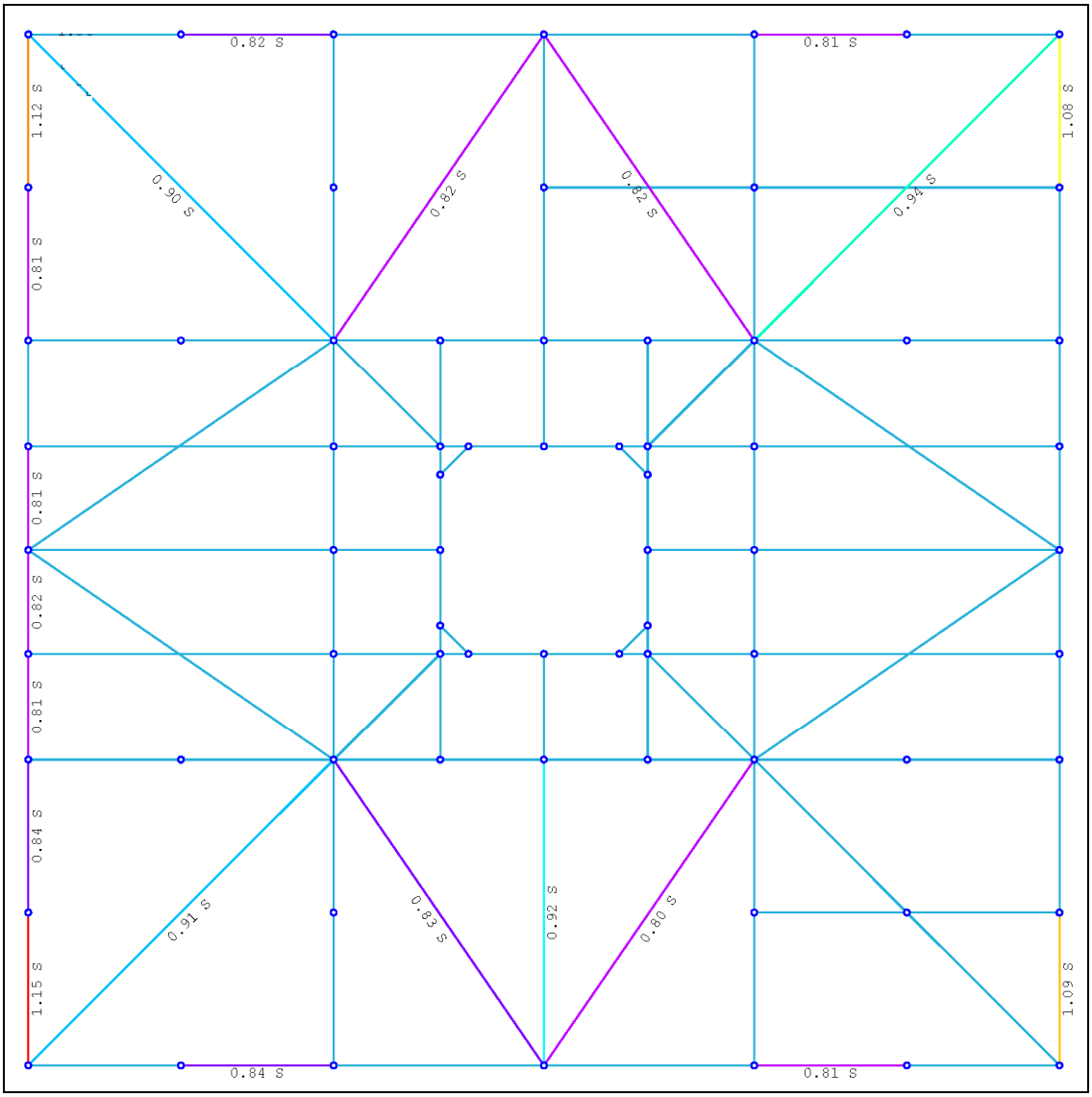


Figure 3-57. Lower Deck Members with Stress Ratios > 0.80 – Fabrication Phase

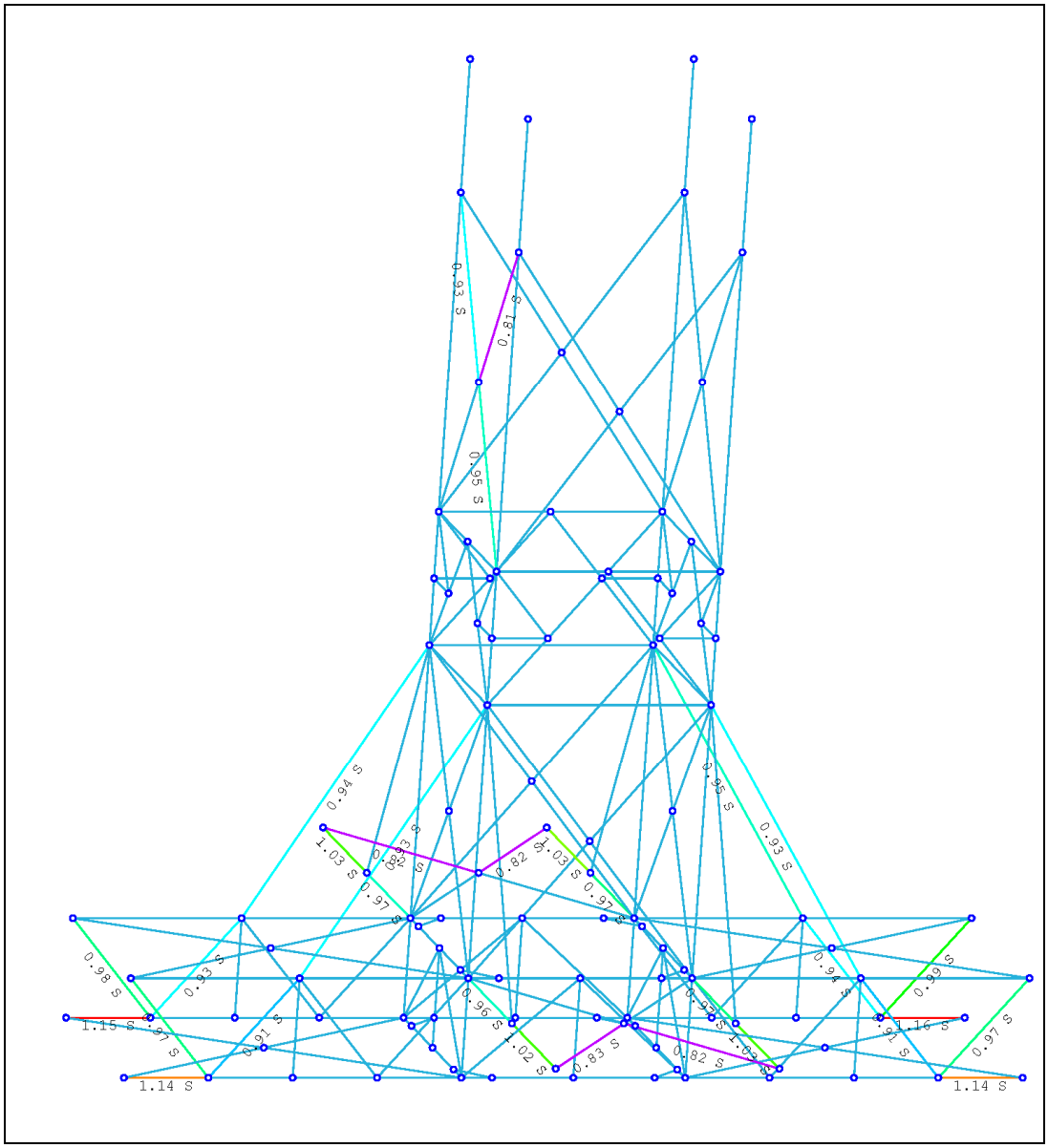


Figure 3-58. CWP Supporting Structure Members with Stress Ratios > 0.80

3.3.1.5.4.4 Global Structural Deck Analysis Results for Full Production Phase

The global static and dynamic structural analysis of the deck model was performed for the 10 MW full production condition, using the load combinations defined in Table 3-17. A total of 39 load cases were computed for dynamic analysis during Full Production Phase. The structure was checked for strength as per API RP-2A for both girders/beams and tubular members.

Figure 3-59 shows the members with stress ratios greater than 0.8 for the static analysis. Localized high stresses can be resolved in more detailed design. Figure 3-60 shows members with stress ratios greater than 0.8 for the dynamic analysis with the maximum stress ratio of 0.94.

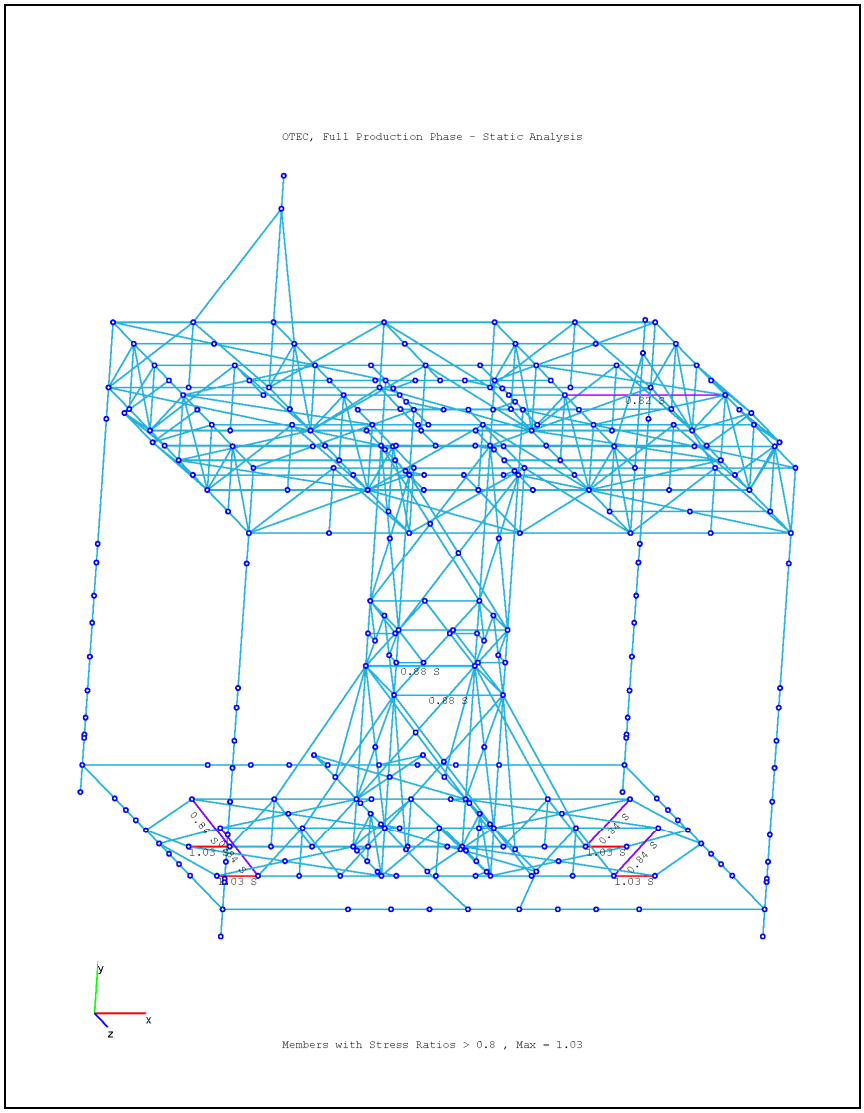


Figure 3-59. Members with Stress Ratios > 0.80 (Max: 1.03) – Full Production Phase (Static Analysis)

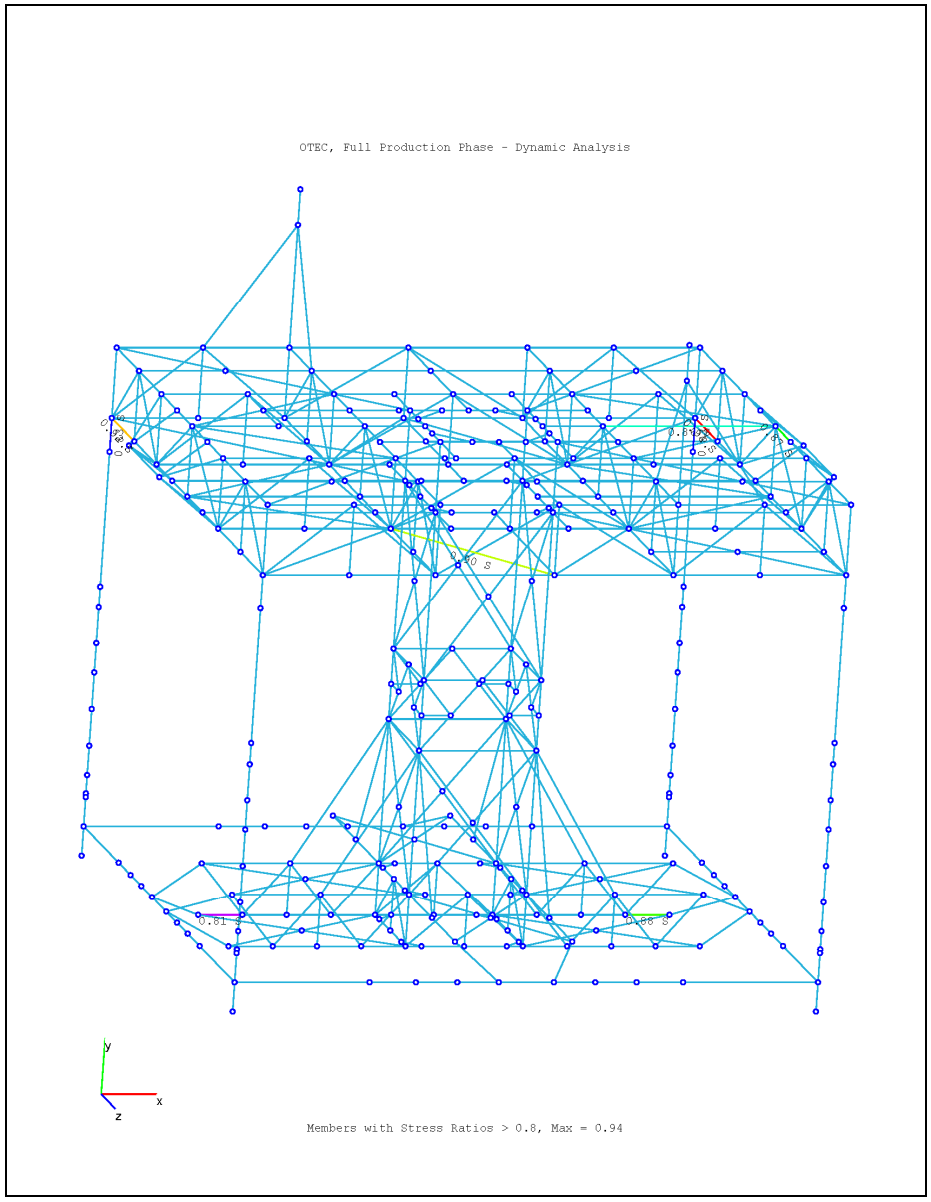


Figure 3-60. Members with Stress Ratios > 0.80 (Max: 1.03) – Full Production Phase (Dynamic Analysis)

3.3.1.5.4.5 Global Deck Structural Analysis Summary and Conclusions

Detailed analysis stress plots are included in Appendix 3.3-6. The following conclusions are summarized for the global structural deck analysis:

Fabrication Phase:

The foundation girders at around the CWP fabrication tower supports have a high unity check ratios due to shear.

The maximum unity check for deck posts is determined to be 1.00.

The maximum unity check on the lower deck was determined to be 1.15. There are four members with unity checks above 1.00 due to out of plane moment. These members will require local reinforcement during detailed joint design phase.

The maximum unity check on the CWP supporting structure was determined to be 1.15. There are eight members with unity checks above 1.00 at the connections with pontoon. These members will also require local reinforcement during detailed joint design phase.

The CWP support frame has sufficient stiffness requirements of 10^8 N/m at Grippers and Guides.

Relative deflections of CWP fabrication tower with respect to upper gripper are satisfactory.

Full Production Phase:

The stress ratios for all the members is determined to be below 1.00 except at the pontoon connections of CWP supporting structure (max = 1.03).

3.3.1.5.5 Hull Structural Design

A conceptual design for the hull primary structure of the Pilot Plant was developed by Horton Wison Deepwater (HWD). Included in this design were the hull sizing, principal dimensions, compartmentation and hull scantling with plate thicknesses, stiffener sizes and girder sizes for all major structural components in the hull.

A Global finite element analysis model was developed for the full production platform, including both Remora units and analyzed for the 100 year wave condition. This analysis will control the primary steel of the hull and provide confirmation whether the hull scantling design is feasible and acceptable for the on-site conditions.

3.3.1.5.5.1 Hull Scantling Design

The initial hull scantling design for the primary hull structure was completed by HWD in accordance with the ABS Classification rules and guides. The type of semi submersible hull is called: the Multi Column Floater (MCF). Four small columns are built on each corner of a square pattern of pontoons and are essentially supporting the decks on the top.

All panels throughout the hull are stiffened plates, using built-up girders and inverted angular stiffeners, designed to be efficient in weight while maintaining a reasonable number of different member sections for fabrication consideration.

After global finite element analysis is completed for a full set of environmental conditions, the global stresses can be used to verify the hull scantlings for strength and buckling. The structural scantling drawings are included in HWD's report.

3.3.1.5.5.2 Hull Global Structural Analysis

Global structural analysis is used to confirm the initial structural scantlings by computing global finite element stresses and checking the plates, girders and stiffeners for strength and buckling. Global structural analysis includes the following steps:

(1) Finite element model development

(2) Control Element Group Selection

(3) Mass calibration

(4) Design wave selection

(5) Load and boundary condition development for static and dynamic load cases

(6) Finite element analysis

(7) Post processing to identify controlling conditions

(8) Strength and buckling checks

These steps are described in more detail in the following sections.

Global structural analysis was performed for the full production pilot plant, which provides the most severe loading pattern into the hull in the 100 year cyclone. To find the loading direction that excites the highest stresses, eight headings at 45º increments were applied in the analysis.

3.3.1.5.5.2.1 Analysis and Design Tools

In general, analysis models are developed in ANSYS and mass calibrated to the required design condition. The mass matrix and wetted panels are transferred to the WAMIT software for hydrodynamic analysis. Load files containing inertial loads (accelerations) and wave pressures are mapped to the ANSYS model for structural analysis. Finite element stresses are used for structural verification as described in the sections that follow. A summary of the critical software systems used in the design process is given below.

3.3.1.5.5.2.1.1 ANSYS V11.0

ANSYS is a general-purpose finite element analysis (FEA) program used extensively for hull design. The ANSYS element library includes beam elements for decks and trusses, shell elements for hull plating and local stiffening details, and solid elements for castings or very detailed local analysis. The program supports linear elastic analysis in addition to non-linear analysis for plastic material behavior or other non-linear phenomena. The ANSYS program includes pre-processing for developing models in addition to post processing tools for reviewing results.

3.3.1.5.5.2.1.2 WAMIT V6.1 (Wave Analysis MIT software)

The WAMIT program performs frequency-domain hydrodynamic calculations on complex structures, with a high degree of accuracy and efficiency. The program is widely recognized in the offshore industry for its floating system analysis capabilities. Principal input to the program consists of a geometrical description of the wetted hull surface, mass matrix, center of gravity location, and global mooring stiffness matrix. Program output includes motion response amplitude operators (RAOs) and hydrodynamic wave pressures. The WAMIT output is post processing using in-house software to develop and map loads for structural analysis.

3.3.1.5.5.2.2 Finite Element Structural Analysis Model

An integrated global structural model was utilized for this analysis. The model included a simplified deck model, along with a fine-meshed model of the hull and a coarse meshed model of both Remoras. The deck model was built using BEAM44 elements and was simplified to just provide the stiffness needed for the analysis. For the hull, shells and plates are modeled as SHELL63 elements, and all girders and stiffeners are modeled as BEAM 44 elements with proper offset to the attached plating. The hull mesh contains one element for each structural panel bounded by stiffeners and girders. The Remoras are built in a simplified way using SHELL63 elements only. The truss section was combined into one large equivalent round section for ease of pressure application. The correct equivalent stiffness values have been applied for each of the three Remora sections but no stresses are read for their design in this analysis. The CWP and the ducting have been included at their C.G. locations using MASS21 elements.

The model and analysis use the International System of Units (SI) with all dimensions in mm, forces in Newton and stresses in MPa. The material properties used for the 355 MPa yield strength steel are as follows:

- Young's Modulus (E): 206,000 MPa
- Poison ratio: 0.3
- Density basis: 7.85 mt/m3 (exact densities vary due to mass calibration)

The total number of elements in the global model is around 56,000 and the total number of nodes is around 43,000. Model plots are shown in Appendix 3.3-7. Figure 3-61 contains a typical plot of the global structural analysis model.

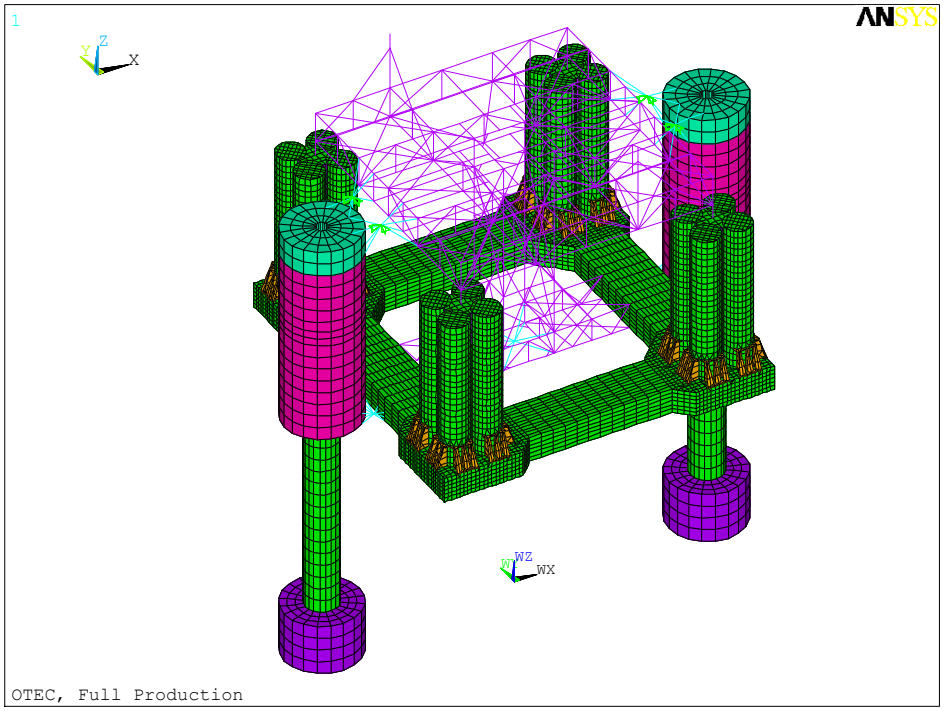


Figure 3-61. Global Structural Finite Element Model

3.3.1.5.5.2.3 Control Element Group Selection

To facilitate stress results interpretation, element control groups have been defined in the semi hull representing critical areas of interest in the structure. These control element groups were broken down into locations in the deck to column, column to node, node to pontoon connections and pontoons. Each control group consists of multiple elements around the hull and represents a characteristic location for either global strength or fatigue.

3.3.1.5.5.2.4 Mass Calibration

Mass calibration of the model was performed in ANSYS to adjust mass and center of gravity (CG) location to match the key figures summary table and sizing basis for the specific platform configuration. Reaction forces for the static and dynamic conditions were checked and verified to be within a tolerance of 1%.

All structure supporting the cold water pipe (CWP) and ducting was modeled and mass elements were used to include the dynamic effect in the analysis. No masses were modeled for mooring lines and support locations. The mass contribution of these items is contained in the dynamic force data applied at the interface locations (vertically at the chain jack locations and laterally at the fairlead locations).

The mass calibration procedure includes a global balancing step that is performed after the finite element models are calibrated to the desired condition with all ballast tanks empty. The balancing procedure computes the required trim ballast amounts for each ballast tank to achieve an overall system balance, taking into consideration all weights, forces, mooring tension, etc. The ballast configuration is then modeled using mass elements in each ballast tank and the final overall weight and CG are matched to the Global Weight Report. The mass matrix for the fully balanced model is then used to develop hydrodynamic loads using WAMIT.

3.3.1.5.5.2.5 Design Wave Selection

Global structural strength analysis was performed using design waves, regular waves that were calibrated to give the same response as the extreme response determined from spectral analysis. For the semi hull, the design waves were selected based on the following primary loadings:

- Deck acceleration, which controls the connections of the hull to the deck and remoras to the deck.
- Hull pry/squeeze forces, which control the column to node and pontoon to node connections.

The selected design waves are conservative compared to the metocean data but are selected to provide the correct response. The primary objective is to analyze a set of regular waves that will develop a conservative estimate of the global stresses for structural design.

The selected design waves are shown in Table 3-18.

Table 3-18. Design Wave Selections

Load Case No.	Load ID	Heading (deg)	Wave Period (sec)	Design Wave Height (m)	Dominant Loading
1	PSH08	0	8	17.36	Pry-Squeeze
2	PSH10	0	10	13.83	Pry-Squeeze
3	PSH21	0	21	4.86	Acceleration
4	PSH09	45	9.5	25.55	Pry-Squeeze
5	ACQ21	45	21	6.86	Acceleration
6	ACB11	90	11	18.93	Acceleration

3.3.1.5.5.2.6 Loads and Boundary Conditions

The vertical mooring loads are applied as forces on the top of columns at the chain jack locations. For the lateral mooring constraints, 10% of the vertical mooring loads is taken and applied as spring elements at the fairlead locations.

The water plane stiffness of the semi and remoras is modeled as vertical springs at the keel of all nodes around the outer shell perimeter. The stiffness constant remains the same for all cases and is a relation between the seawater density and total column area. The free ends of the springs are fixed in translation. A plot of the model showing the boundary conditions is shown in Figure 3-62.

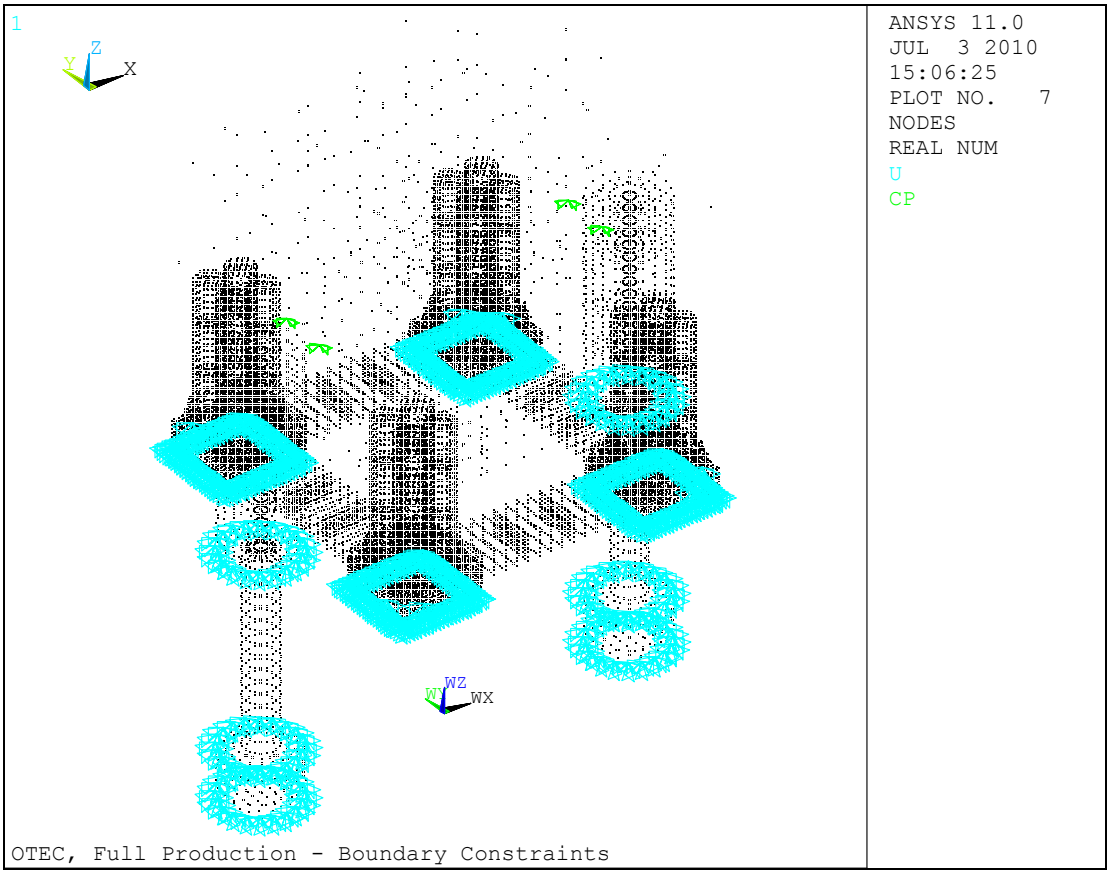


Figure 3-62. Boundary Conditions for Global Finite Element Analysis

Hydrostatic pressures (static load cases) and hydrodynamic pressures (dynamic load cases) were applied as pressure loads to the wetted elements.

Hydrodynamic loads are developed by the global performance group for application to the global structural model. The wetted elements from the global structural analysis model are used directly as WAMIT panels for hydrodynamic analysis. In addition, the mass matrix from the calibrated structural model is transferred directly to WAMIT for analysis. This process ensures compatible loads and accelerations in the integrated hydrodynamic/structural analysis.

Note that hydrodynamic and hydrostatic pressures are typically applied below the water line for structural analysis, taking into account the mean draft for the condition being analyzed. For scantling above the water line, the wave pressure is taken to be the value calculated at the water line. This dynamic pressure is used from the water line to the 100-yr maximum wave crest elevation. Internal structure (bulkheads, flats, etc.) above the water line are analyzed using a design head based on classification society rules for internal tanks and voids. A plot of the model showing the hydrostatic pressure application is shown in Figure 3-63.

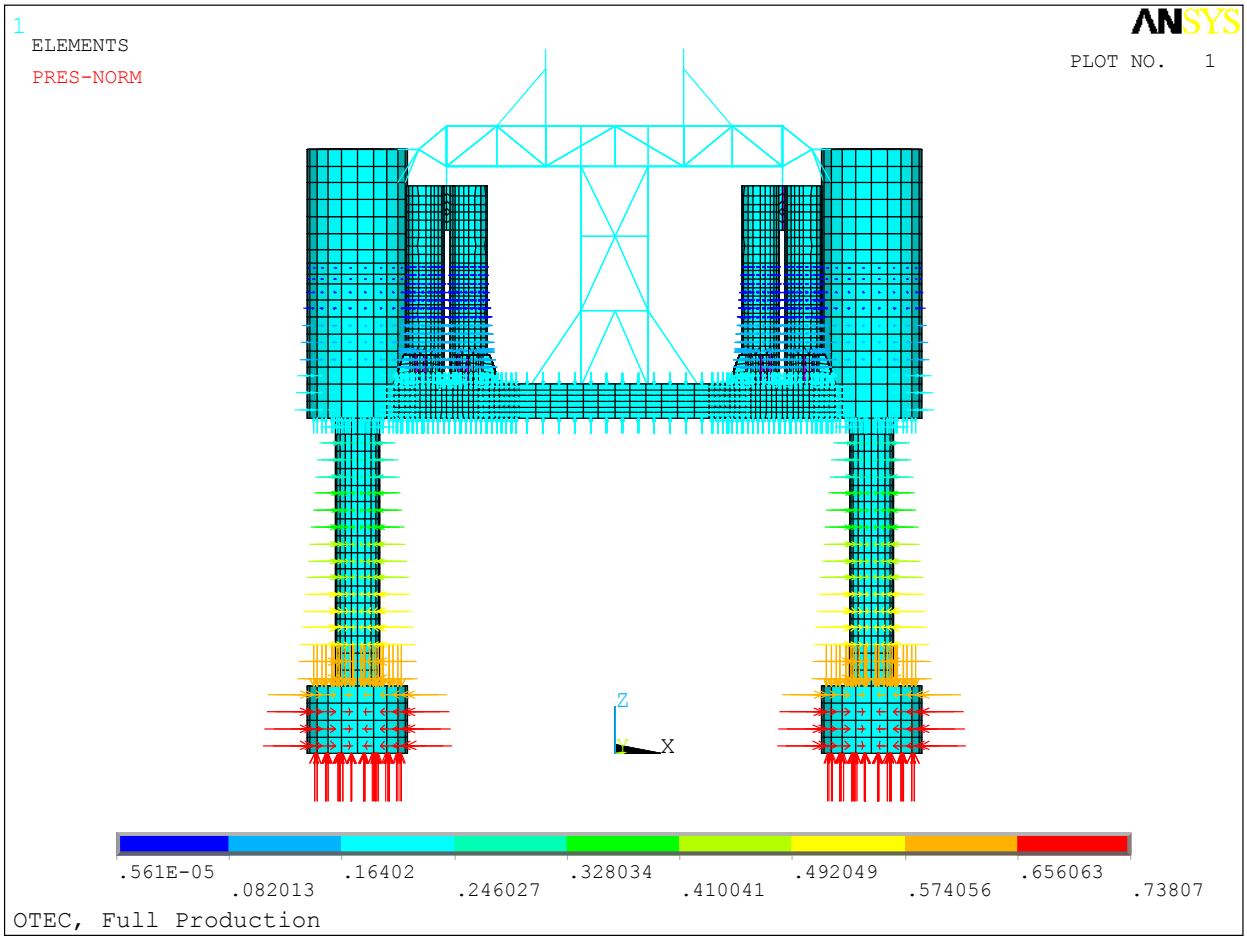


Figure 3-63. Pressure Loads for Global Analysis

3.3.1.5.5.2.7 Analysis Results

Results of the global in-place analysis are presented in the form of datasheets and corresponding ANSYS stress plots. Included are static stress plots of the major hull components in Appendix 3.3-7. Combined (static and dynamic) component stress plots for buckling design are also shown in Appendix 3.3-7, as are the combined equivalent stress plots for strength design. The increase of stress safety allowable for the 100 yr cyclone is 1.67. With an operating stress allowable of 0.6 FY, the allowable Von Mises stress is 355 MPa (0.6·355·1.67).

For each of the eight headings and six design waves, real and imaginary stress data were scanned and sorted according to the magnitude of Von Mises stress and cyclic principal stress. To reduce the number of stress plots, no plots have been made where the maximum combined equivalent stress (static plus dynamic) was less than 100 MPa.

All control groups that showed a combined von Mises stress greater than 100 MPa were reviewed in detail to identify load combinations for stress plots. The scan results for all control element groups are shown in Table 3-19.

Table 3-19. Maximum Global Stresses for Control Groups

Control Group nr.	Heading: (degree)	Wave height (m)	Period: (sec)	Element number:	node number:	Phase angle (deg):	σstatic:	σcombined:	Ratio: (σ_c / σ_s)
C01	45	25.55	9.5	16627	14752	-30	61	537	8.80
C02	45	25.55	9.5	21383	733	145	49	103	2.10
C03	45	25.55	9.5	26749	23682	95	55	126	2.29
C04	45	25.55	9.5	26299	779	-35	78	112	1.44
C05	45	25.55	9.5	16882	15030	145	81	321	3.96
C06	45	25.55	9.5	18469	15030	140	70	300	4.29
C07	45	25.55	9.5	29805	19126	-35	70	205	2.93
C08	45	25.55	9.5	23918	21794	130	35	87	2.49
C09	45	25.55	9.5	21656	19455	140	34	48	1.41
C10	45	25.55	9.5	2981	140	-40	31	202	6.52

All control groups were below the allowable stress except control group C01. The location of C01 is the connection of the pontoon to the remoras. It is merely a lack of support reinforcement in the finite element (FE) model that excites the stress at this location. Adequate insert plates and backup structure should be incorporated in a next cycle of analysis, which will take the high stress down to acceptable level.

The low combined stresses compared to the allowable stress are not very high overall, which confirms global structural strength and provides not only reserve capacity for local design and buckling checks but also room to optimize the design and weight.

This global analysis captures the global structural behavior of the hull but the identified load cases and cut boundary loads can be used for local model analysis.

As the hull structure is prone to fatigue damage due to the dynamic wave loading during its service life, global spectral fatigue analysis will have to be performed to identify the fatigue sensitive locations. The high ratios between combined and static stress indicate that fatigue may be of larger concern due to the interaction of the three floating bodies (semi and two Remora units).

3.3.1.5.5.2.8 Hull Structural Analysis Conclusions

The primary conclusion is that the initial scantling design is acceptable and includes reasonable margins and contingencies appropriate to this conceptual stage of design. Weight reduction is a recognized option through scantling design optimization. However, the current scantling provides a conservative hull design for this study.

The ratio of dynamic stress to static stress indicates that fatigue analysis should be completed early in future design phases to identify any necessary reinforcement required for fatigue strength and to confirm whether castings are required at pontoon-to-column connection locations.

3.3.1.5.5.3 Remora Connections to Platform

Multiple analysis runs where different constraint mechanisms were tested for the Remora connections have resulted in the following favorable types of connection design:

At the pontoon level, two connections are required that have the capability to fix relative motion in all three directions. This is made possible through two horizontal cylindrical pins which are engaged into a hook type structure. Proven designs are available in the industry. See Figure 3-64 and Figure 3-65 for examples.

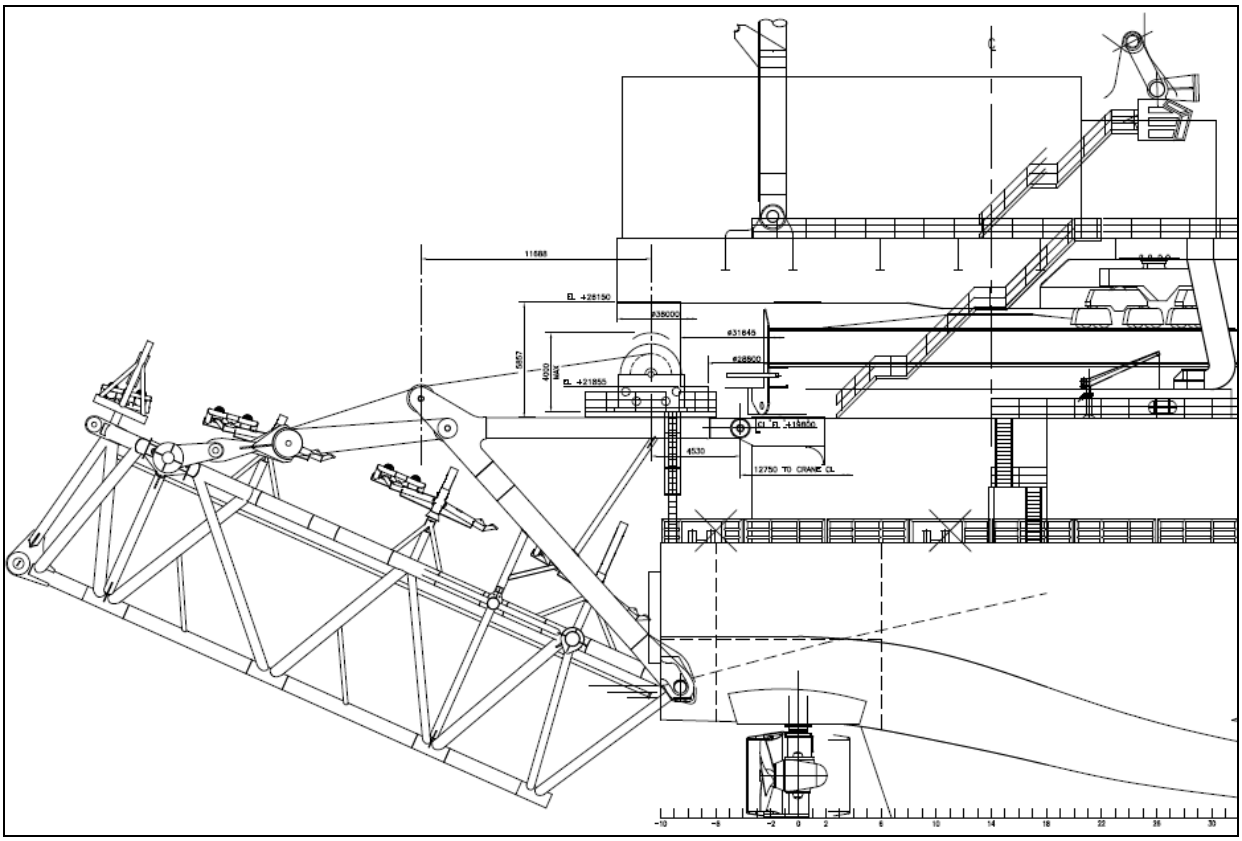


Figure 3-64. Pin Connection Example

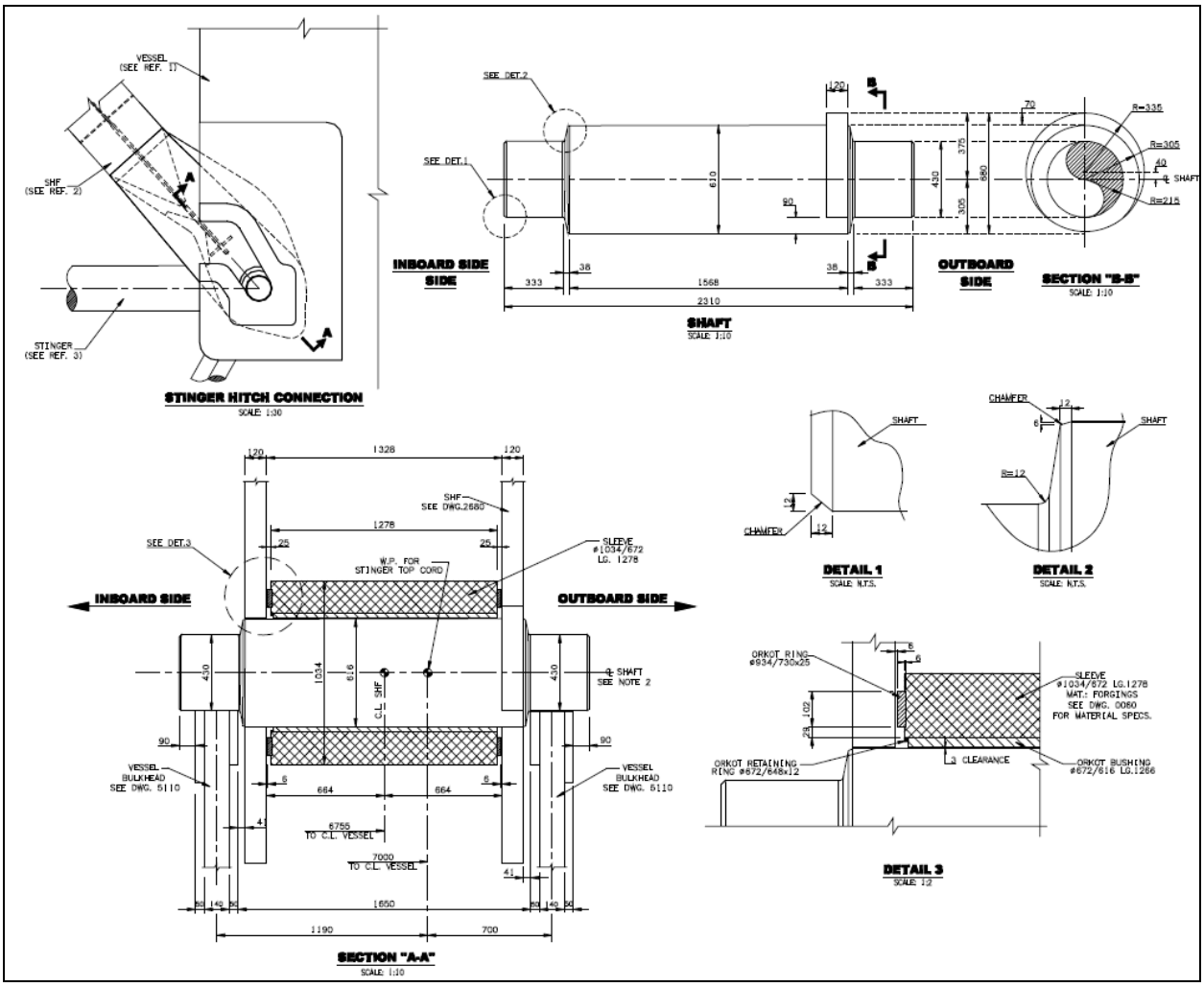


Figure 3-65. Pin Connection Detail

At the deck level, two connections are required that have the capability to fix relative motion in lateral directions only and with free/sliding capability in vertical direction. This is possible through cylindrical pins that are mounted vertically with a sleeve type structure that allows vertical relative motion between the remora and deck. The maximum measured vertical relative motion is 70 mm.

With the above mentioned constraints, reactions have been extracted from the analyses, which are summarized in Table 3-20 below.

Table 3-20. Reaction Loads at Remora Connections

Nr.		Load case	phase (°)	node nr.	Fx (kN)	Fy (kN)	Fz (kN)
Remora to Deck Connections		4	175	42712	-4825	-4057	0
		2	175	42713	-1889	1016	0
		4	0	42713	1852	1416	0
		4	-175	42715	4587	4063	0
		2	5	42714	-1762	701	0
		4	0	42714	84	-1890	0
Remora to Pontoon Connections		4	-5,0,5	42711	18496	8269	-5905
		2	0	42710	7116	-2343	-1337
		4	-175	42710	561	-3247	35
		6	5	42710	1668	348	-4045
		4	175,-180	42709	18949	7787	6434
		4	-5	42709	18925	-8479	-6153
		2	175	42708	7647	-2196	1923
		2	-10	42708	-7478	2795	-970
		6	170	42708	1775	664	4278

Based on the reaction loads above, a minimum required pin diameter is calculated to be Ø130 mm for the deck connection and Ø236 mm at the pontoon level. Both pin diameters are considered of reasonable design. The 236 mm pin can be reduced if the connections are brought out further (away from each other), which will decrease the reactions at nr.5 and nr.7. This Remora to platform connection will need to be further developed in the next phase of work.

3.3.1.6 Platform Risks

The platform is considered a low risk component. About 100 semi-submersibles have been built for the offshore including 70 mobile offshore drilling units currently in service, 15 deepwater production semi-submersibles and about 20 converted drilling semis presently producing. The MCF is a novel design, but it follows practices already implemented on the Red Hawk cell spar[xi]. In any case, a conventional semi-submersible design could be used. The choice between an MCF and a conventional semi is a commercial one and will be based on the country and or yard in which the platform would be built.

3.3.1.7 Platform Design Forward Plans

The platform design and analysis performed in this phase of project are considered in the conceptual development level. The following Table 3-21 is a list of engineering tasks that need to be performed as a minimum to further mature the design of the platform concept.

Table 3-21. Platform Forward Plan Work List

	Plan	Phase
1	Preliminary Stability Analysis	Pre-FEED
2	Stability Report (for Class Approval)	FEED
3	Piping & Instrumentation Drawing	Pre-FEED
4	Model Basin Tests	Pre-FEED
5	Classification Drawings (for Class Approval)	FEED
6	Final Structural Analysis Report (for Class Approval)	FEED
7	Final Global Analysis Report (for Class Approval)	FEED
FEED: Front End Engineering Design		

Front End Engineering Design (FEED) is a term used in the offshore industry to define "Final Design" in preparation for soliciting fabrication and construction bids. While the definition of FEED is not precise, generally it may start when the concept is selected ("frozen"), all design criteria are fixed (metocean, geotechnical, throughputs, etc.) and there are no more significant technical unknowns. The output of FEED is a bid package with a design specification, classification drawings (for approval by a classification society), plus associated reports describing the analysis and testing to support the design.

3.3.1.8 Stationkeeping (A1300)

A1300 Stationkeeping Element - Assumptions and Terminology

The OTEC Pilot Plant is assumed to be located off of Barber Pt. on Oahu in Hawaii as further described in Section 3.6. The semisubmersible platform will support a 4m Cold Water Pipe (CWP) that extends to a depth of 900m, an attached heat exchanger and pump system (referred to as a remora), and a power cable that extends from the plant to the base at Pearl Harbor. The Pilot Plant is has been defined with two distinct phases:

- Pilot - Test/Demonstration Phase (2 Years)
- Production Phase (20 Years)

The "Pilot" Plant -Test Configuration and will produce 5mW using one remora for the first two years. After this period, a second remora will be added to provide 10mW for the next twenty years. This 10mW plant will be known as the "Production" Configuration. Throughout this section the term "Pilot" will refer to the two-year test/ demonstration project, and "Production" will refer to the 20-year 10 MW power delivery phase. This is important because the mooring loads and regulatory approval requirements are distinctly different for each of these phases. The technical approach for the design of the Stationkeeping Element station has been to:

(1) Specify and design the minimum mooring spread required for the Pilot phase.

(2) Size anchors and tensioning systems for in-situ transition to the Production Phase without the need to make major modifications to the platform or re-install new anchors if possible.

A-1300 Stationkeeping Element - Overall Summary

The OTEC Station Keeping Element (A1300) is part of the Platform Segment and consists of three major Subsystems as shown in Figure 3-66 below. These are the Tensioning Subsystem (A1310), Tensioning Members (A1320), and Seafloor Anchors (A1330). The Tensioning subsystem resides on the Platform corners and is used to pretension the mooring line (depending on capacity, proof loading may be completed w/ the tensioners as well). . The tensioning members are the mooring legs (lines and chain), and the anchors provide holdback force through combinations of weight and embedment on the seafloor.

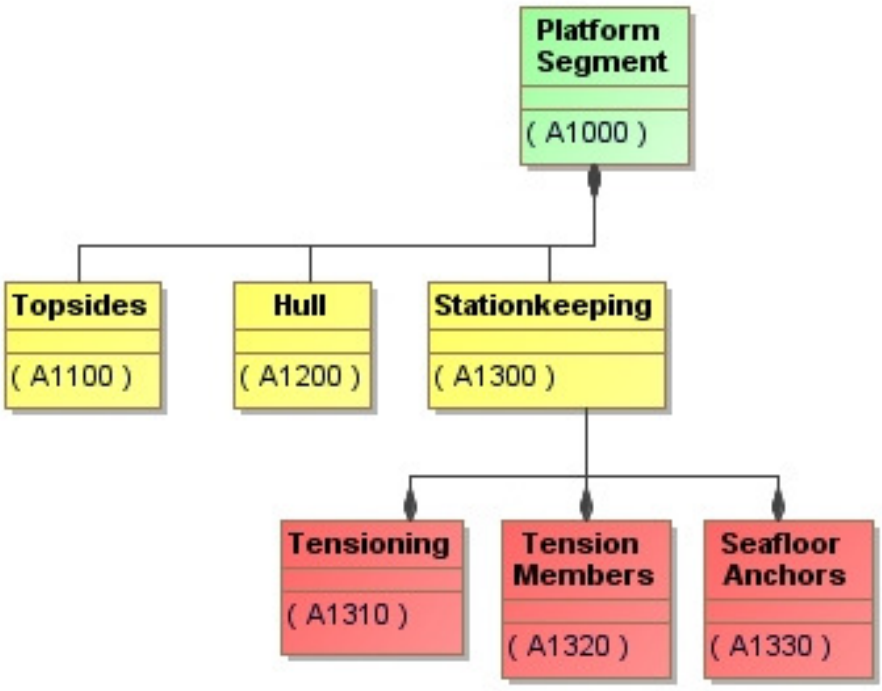


Figure 3-66. Stationkeeping Element

The primary top-level requirements for the Stationkeeping Element are provided in Table 3-22.

Design Decisions/Trade Studies

For the OTEC Stationkeeping Element the following top level trades were addressed:

Mooring type: The main mooring configurations considered were taut moorings and catenary leg moorings (Ref Figure 3-67). While taut moorings are used for some offshore oil platforms, the loads and geometry were not deemed suitable for the Pilot Phase system due to size, water depth, loads, and bottom composition. The catenary mooring leg design was therefore selected to be the baseline for the Pilot Phase platform. A form of taut mooring was used to for the Production Phase.

Table 3-22. Top Level Stationkeeping Requirements

Requirement	Source	Rationale	Impact
Pilot plant will have one remora for a 5mW system	Makai Power Cycle model	Sufficient power output to demonstrate capability.	Mooring loads and installation steps
Pilot Phase is 2 years installation and must survive a 25 year return storm swell	Derived Requirement	2 years test/demonstration period to test and demonstrate OTEC technology	Loads analysis, mooring requirements, installation steps and loads
Production Phase is 20 year installation and must survive a 100 year return storm condition.	Derived requirement	Establish a long demonstrate long-term production of power into DoD facility.	Mooring loads and associated components increased to retain option of production phase in-situ
Watch circle of platform during worst conditions will not cause damage to CWP or power cable	General best practices and method to minimize risk and potential costly damage	Avoid costly damage to power cable and cold water pipe	Scope and pretension of mooring as well as loads on mooring

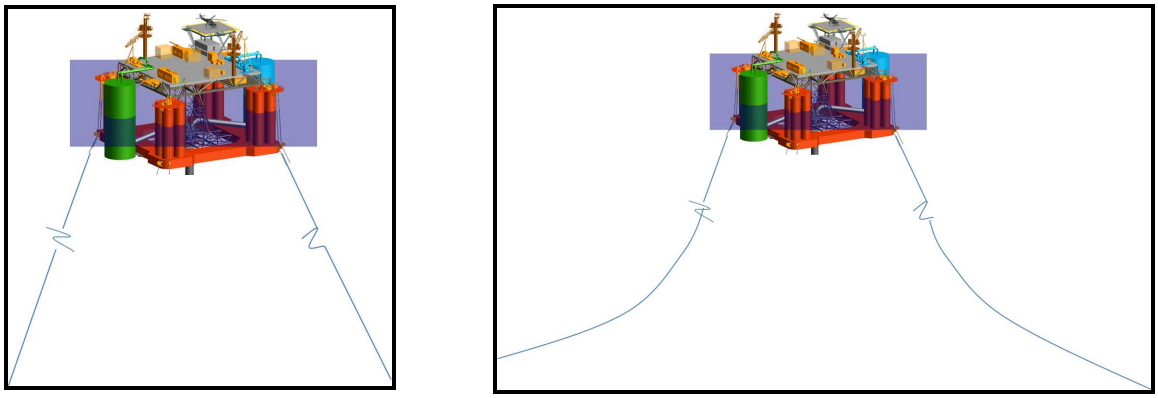


Figure 3-67. Taut Mooring (Left) and Catenary (Right) Mooring Configurations

Number of legs for platform: For both the test and the production phases the number of legs was investigated to determine the optimal solution based on cost and risk. An early decision was to analyze the pilot plant and production plant separately in order to scale back and minimize the initial costs for the pilot plant.

For the Pilot phase the loads were small enough to use a single leg per corner of the platform for a total of four legs as shown in the left side of Figure 3-68. The risk associated with this approach is that in the damaged leg condition, the movement of the platform is of a magnitude that would almost certainly result in damage to the power cable due to dragging along the seafloor. The obvious advantage to the single leg approach is the cost savings for both materials and installation. The cost impact of a damaged power cable however would far exceed this cost savings. For this reason, a two-leg per corner approach is recommended as the baseline design for the pilot plant.

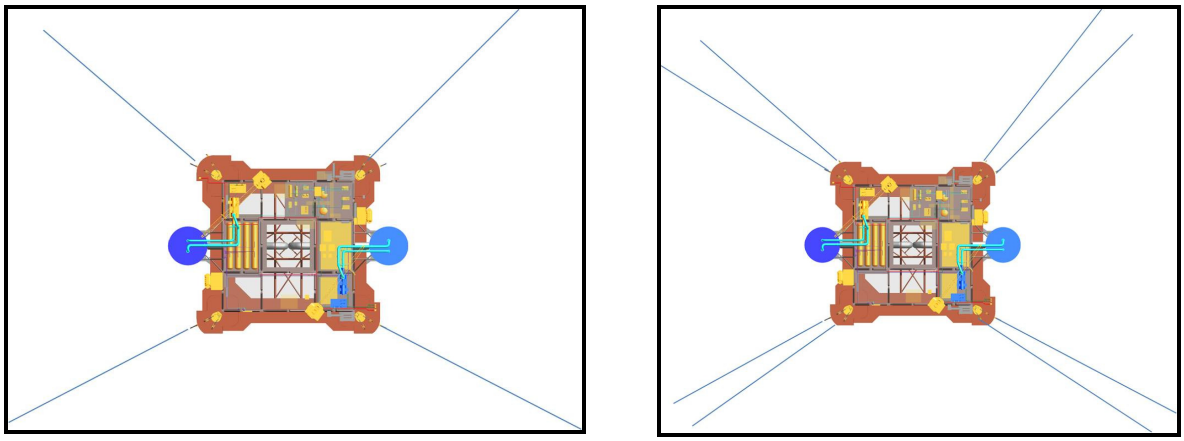


Figure 3-68. Pilot Plant - Four-Point and Eight-Point Mooring Configurations

For the Production Phase the loads are too high to use a single leg per corner with reasonable size mooring components. This, combined with the obvious risk of damage to the power cable in the damaged leg condition drove the design to a minimum of two legs per corner. Refer to the right side of Figure 3-68. There is always the option is to use more than two legs corner. The advantage of more legs is that the loads on any single leg are reduced, especially for the damaged leg condition. This would also reduce the size and loads during installation for the moorings. However, the additional cost is significant for material and installation and at this point it appears that the component sizes and installation loads for a two leg per corner design are within reason. For this reason, the current baseline design for the production plant is two legs per corner. If conditions and/or loads change, additional legs per corner may be revisited.

A1300 - Overall Risks - Stationkeeping Element

The summary of risks for the Stationkeeping element is summarized in Table 3-23 below.

Table 3-23. Stationkeeping Overall Risks

#	Risk	Mitigation
1	Mooring leg damage or loss of a mooring leg	Mooring will be designed and tested in accordance w/ standard codes and practices for offshore platforms to minimize this risk.
2	Damage to power cable due to excessive platform motion.	This risk will be mitigated by designing the baseline mooring w/ sufficient stiffness to maintain a reasonable watch circle for the platform which will be iterated based on the design configuration for the power cable riser section. For the damaged cable condition, more than one leg per corner is the current baseline to reduce excessive motion in this scenario.
3	Mooring anchors slipping during high load conditions	This risk will be mitigated by proof loading the mooring after installation according to codes for offshore platforms.

A1300 - Overall Stationkeeping Element - Forward Plan/Next Steps

For the OTEC station keeping system the detailed design and analysis for the assemblies will be completed once a detailed survey sufficient to complete the mooring and anchor design has been completed. In addition, a detailed Concept of Operations (CONOPS) plan will be constructed for the moorings with steps, loads, handling equipment, vessel support, and personnel requirements included.

A-1300 - Stationkeeping Element - Overall Loads Analysis and Design Implications

To define the overall stationkeeping requirements, the platform IPT defined three mooring configurations and related load cases to be analyzed. These are summarized in Table 3-24 below. The first configuration is the lowest cost configuration to support the Pilot phase and consists of a four-point temporary moor with wire rope as the primary tension member. The second case is an eight-line configuration again using wire rope as a temporary mooring for the two year pilot phase. The third mooring configuration was defined to support the 20-year Production phase and assumed polyester line is used for the main mooring component to meet the service life requirement.

Table 3-24. Pilot Plant - Analytical Load Cases

Pilot Phase	Mooring	Mooring Components	Rationale
Pilot	4- Point Moor	Temporary (2 Year) Wire Rope	Lowest Cost for Pilot Phase
Pilot	8- Point Moor	Temporary (2 Year) Wire Rope	Reduced max loads/line Reduced risk to power cable in case of loss of a mooring line
Production	8 Point Moor	Permanent (20 Year) Polyester Line	Standard Permanent Mooring Configuration to meet 20-year service life requirements

To provide realistic anchor coordinates for the mooring analysis, anchor locations were selected at the Pearl Harbor OTEC site in locations which (a) had minimum slope, and (b) showed some evidence of sediment based on preliminary sub-bottom data. The anchor locations in geographic coordinates are shown in Table 3-25 below. Note that the anchors are placed on two plateaus at water depths of approximately 900 meters and 1570 meters. The plan view of these anchor locations is shown against the site bathymetry in Figure 3-69.

Table 3-25. Anchor Coordinates and Depths - Pearl Harbor Site

Anchor	Compass (deg)	Depth (m)	North Latitude	West Longitude
1	90	900	21.16913774	158.10186538
2	100	915	21.16578022	158.10218085
3	180	1510	21.13766274	158.12260000
4	190	1590	21.13814084	158.12846010
5	270	1575	21.16913889	158.15631698
6	280	1525	21.17459868	158.15580475
7	0	940	21.18847441	158.12260000
8	10	925	21.18826919	158.18898226

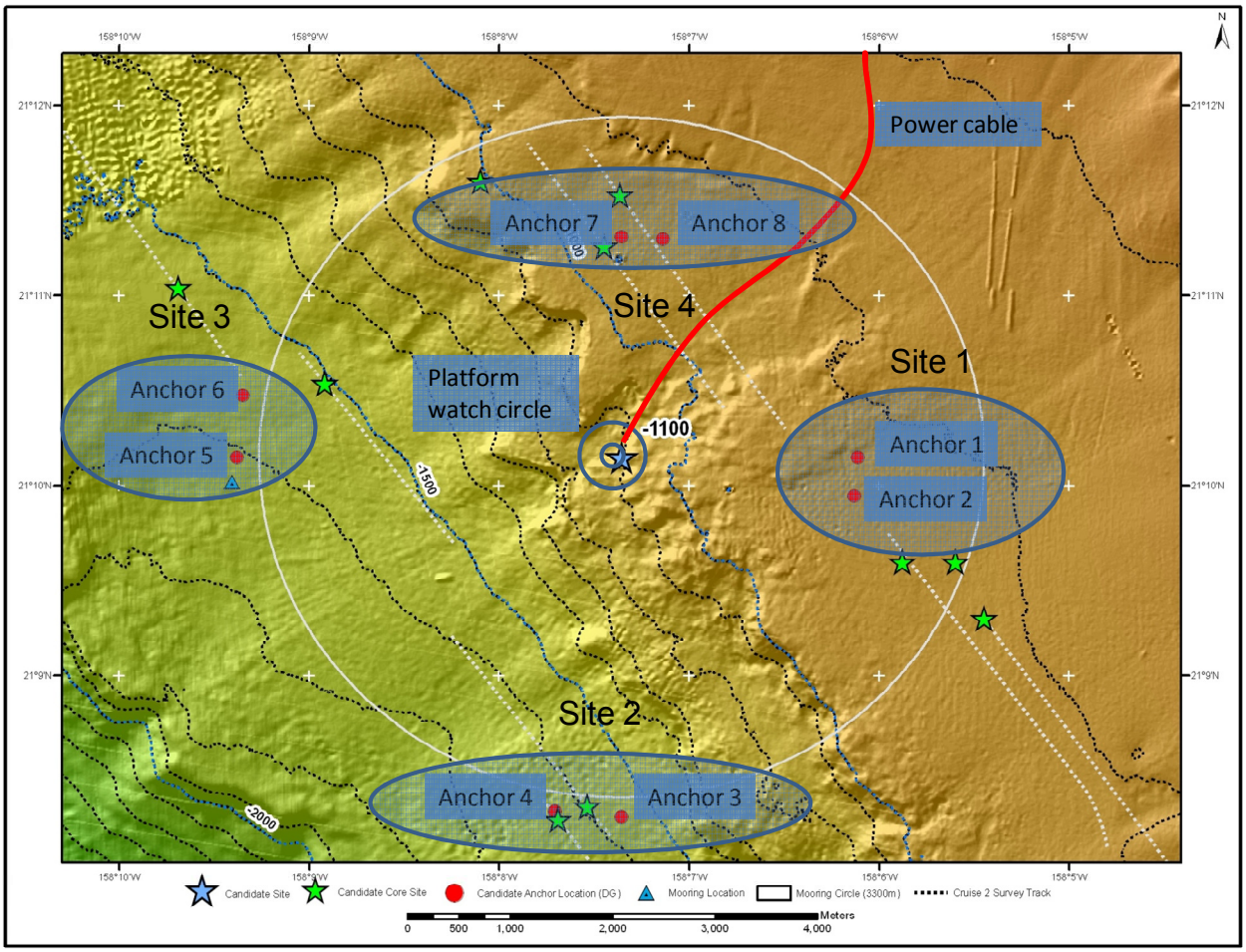


Figure 3-69. Anchor Locations with Bathymetry

Simulations were completed by Horton-Wison for the site mooring geometries previously described and with realistic models of the platform, remora, and mooring configurations assumed[xii] . The maximum load for each of the configurations defined in Table 3-24 was estimated by modeling the platform with a sea state and weather environment appropriate to that service life. For the Pilot phase a 25-year swell was assumed and for the production phase a 100-year cyclone case was assumed. The maximum estimated loads in kN are shown Table 3-26 below. The intact load refers to the maximum dynamic load on any single mooring line with all mooring lines intact. The damaged (or broken line) condition refers to the maximum resulting load after one or more legs has been damaged or lost. The Offset refers to the maximum horizontal excursion of the platform from the nominal stationkeeping hold point with one line lost. Points of significance from a review of Table 3-25 are:

- The maximum offset excursion is reflected in the broken line case for the four-wire Pilot configuration. This amount of offset is undesirable from the perspective of risk to the power cable.

- The vertical (Fz) loads in the wire configurations are low as expected due to the suspended weight of the mooring wire and the catenary mooring configurations.
- The maximum anchor tensions and vertical uplift loads are significantly higher for the production configuration due to the higher environmental loads and the steeper mooring angles resulting from the use of lighter-weight polyester rope for the mooring lines.

Table 3-26. Maximum Estimated Loads and Offsets

				Maximum Forces, kN					
Phase	N Lines	Type	State	Tension Top	Tension Anchor	Fx' (In line with mooring line)	Fy' (Perpendicular to mooring line)	Fz (Vertical)	Offset (m)
Pilot	4	Wire	Intact	2593	2260	2237	59	315	109.1
Pilot	4	Wire	Bkn	2875	2542	2121	1051	403	745.7
Pilot	8	Wire	Intact	1466	1525	1189	954	26	96
Pilot	8	Wire	Bkn	2593	2387	2312	510	300	184.9
Pilot	8	Polyester	Intact	1522	1474	1352	511	291	23.7
Pilot	8	Polyester	Bkn	2593	2483	2307	583	710	52.2
Prod	8	Polyester	Intact	4852	4579	4374	41	1355	77.2
Prod	8	Polyester	Bkn	8228	7990	7532	113	2665	147.8

These loads were then used to size the specific mooring subsystem components including tensioners, fairleads, tension members, and anchors. The following sections describe each of the subsystems which comprise the Stationkeeping element as shown in Figure 3-66. These include:

- A1310 - Tensioning Subsystem
- A1320 - Tension Members
- A1330 - Seafloor Anchors

A1310 - Tensioning Subsystem:

The tensioning subsystem is platform mounted and provides a method of pre-tensioning the mooring legs during installation. It may also be used to proof load the anchors if the capacity is sufficient. It consists of the tensioner, the mooring chain stopper that takes the platform loads after installation, and any fairleads used to route the mooring legs at the platform interface. The requirements for the tensioning subsystem are provided in Table 3-27.

Table 3-27. Tensioning Subsystem Requirements

Requirement	Source	Rationale	Impact
Utilize standard commercially off the shelf product for tensioning and stopping off load	Derived requirement	Using existing technology to reduce costs and risks	Selection of tensioner components
Platform watch circle is small enough to ensure no damage to the power cable or cold water pipe	Derived requirement	High cost of cable and CWP and need to minimize risk of damage	Sets a minimum level the tensioner must meet to pretension the system adequately
Proof load drag embedment anchors to 80% of max intact load	API RP 2 SK requirement	Sets anchors and reduces risk of dragging during period of performance	Requires tensioner or other device be employed to tension each anchor as it is installed
Plant interface for tensioner, mooring tensioner, chain fairlead, and chain stopper to be designed for production plant loads	LM team derived requirements	Eliminates costly platform and equipment retrofit after 2 year period	Tensioner size, platform interface design, chain size (since driven by tensioner), fairlead and chain stopper size.

A1310 - Tensioning Subsystem - Functional Block Diagram

The functional block diagram for the tensioning subsystem is shown in Figure 3-70 and consists of the tensioner, mooring chain stopper, and fairleads as configured to meet the number of tension members installed. There is a single tensioner windlass on each corner and a pair of chain stoppers and two fairleads for each mooring leg installed off of each respective corner.

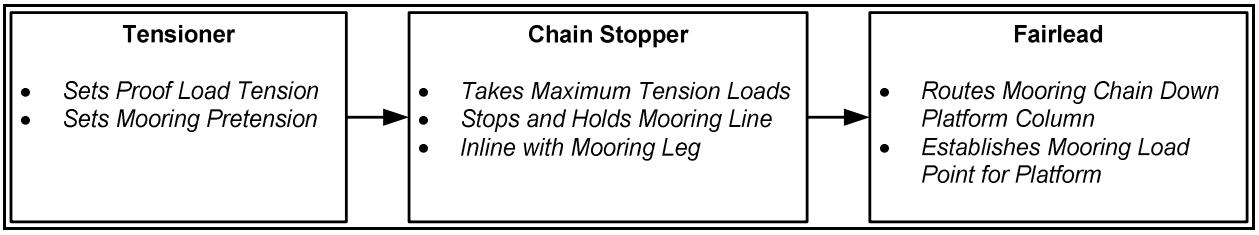


Figure 3-70. A1310 Tensioning Subsystem - Functional Block Diagram

A-1310 Tensioning Subsystem: Design Decisions/Trade Studies:

There are primarily two types of tensioning mechanisms used for mooring offshore platforms. Both are normally hydraulically driven due to the loads and availability of hydraulic power.

- Vertical axis windlass: Normally mounted on the deck of the platform with the mooring legs routed through fairleads to it. It has a chain gypsy which keys to the chain links and increases or relieves tension as the gypsy turns.
- Linear chain jack: Normally mounted on the vertical leg in line with the mooring legs. Because it is mounted in line with the legs it does not require a fairlead at the deck level. The chain jacks use hydraulic cylinders and use pegs to pick up the chain one link at a time, slowly increasing tension as the chain is pulled up.

Because the designs and mounting interfaces for these tensioners are so different, they are not normally interchangeable on a platform. Once the baseline tensioner system has been selected, the platform interface and accompanying loads analysis and design details are completed accordingly.

The main tradeoff for the tensioner selection is the number required for the platform and whether there is a requirement for active positioning. The OTEC system does not require active positioning, and thus does not need active control over each line during operations. Due to its design, there must be a linear chain jack tensioner for each of the legs while the vertical axis windlass may tension multiple legs per corner, one at a time. Thus for platforms with multiple legs per corner, the vertical axis windlass can result in significant cost savings. Even though additional fairleads are required to route the mooring legs to the windlass, the cost of these is more than compensated by the savings achieved by eliminating one or more tensioners per corner. For this reason, the vertical axis windlass has been established as the baseline tensioner for the OTEC station keeping system.

Another trade study investigated the capacity requirements for the tensioner components. The Pilot Phase loads are significantly lower than the Production Phase loads. If the tensioning system is designed only to meet the Test Phase conditions, the size and costs for the initial system will be significantly lower than that required for the Production Plant. The tradeoff is that the tensioning system components and platform interfaces would need to be replaced at sea after the initial Test Phase which would be very costly and include some level of risk. For this reason, the decision was made to design and size the tensioner system for the Production Plant loads.

The chain stoppers and fairleads are standard products and these designs are mature for offshore platform applications. For this reason, no trades were deemed necessary for these components. The impact of this decision is that the chain which indexes to the tensioner, must be the size needed for the production plant. For this reason, both the tensioner components as well as the chain will be significantly overrated for the initial Pilot Phase.

Platform tensioners are normally rated based on the pre-tensioning requirements for 30% of the Break Strength (BS) of the chain. They are not rated to hold back against the full design loads on the platforms since these are significantly higher. These loads are held back by the chain stoppers. Once the mooring legs have been tensioned, chains are stoppered-off and the load on the tensioner is relieved allowing the systems to be serviced or repaired if required.

In addition to pretension the mooring legs, the tensioners need to be sized to support the mooring proof loads during installation. For offshore platforms like the OTEC platform, this proof load is normally 80% of the maximum intact condition load based on the platform mooring loads analysis. This proof load may be applied using either an installation vessel or the platform. The advantage of using the platform is the installation vessel bollard pull requirement is significantly reduced and the load may be applied in a very controlled manner by the platform tension. One corner is tensioned on the platform and the opposite corner is stoppered, allowing two legs to be load tested simultaneously. Depending on the required proof load, this may drive the tensioner capacity up so a cost trade must be established prior to final decision.

A1310 - Tensioning Subsystem Design Configurations

Representative illustrations of the corner-mounted windlass and chain stopper are shown in Figure 3-71 below. The corner configuration a two leg configuration is shown in Figure 3-72 below. For the Pilot Plant, the tension members will consist of 200 m of R5 Studless link chain rated for production phase loads at platform tensioner[5]. This will provide adequate length for pretension allowance and opportunity to make position and/or tension adjustments as required.

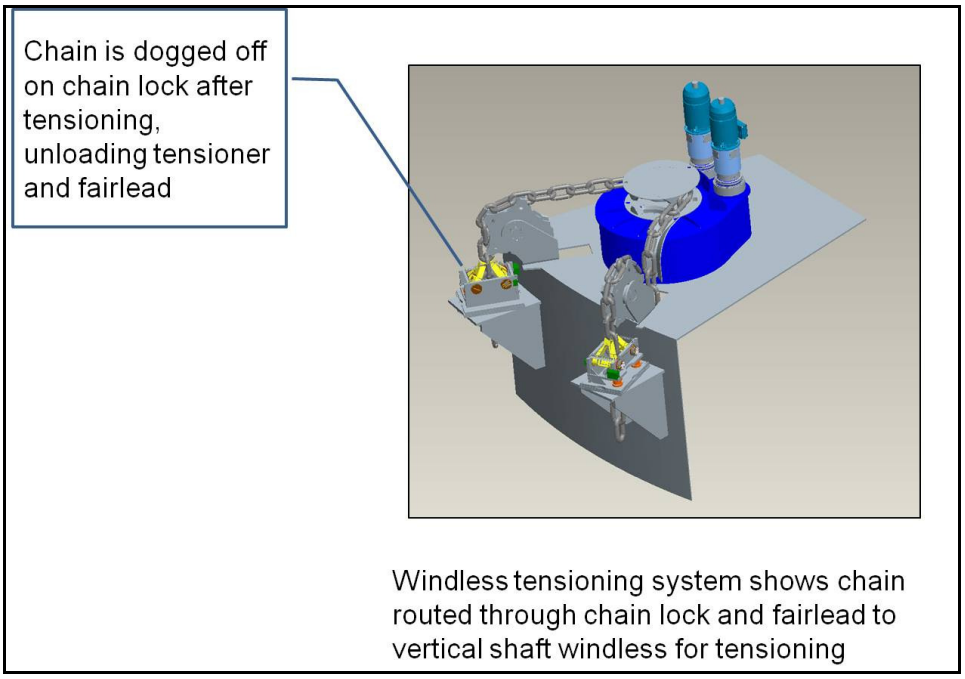


Figure 3-71. Corner Windlass and Chain Lock

[5] Analysis was performed using 105 mm diameter R5 platform chain. Commercially this is difficult chain to procure and it is likely that the final design will substitute 115 mm R4 chain which would have equivalent corroded strength.

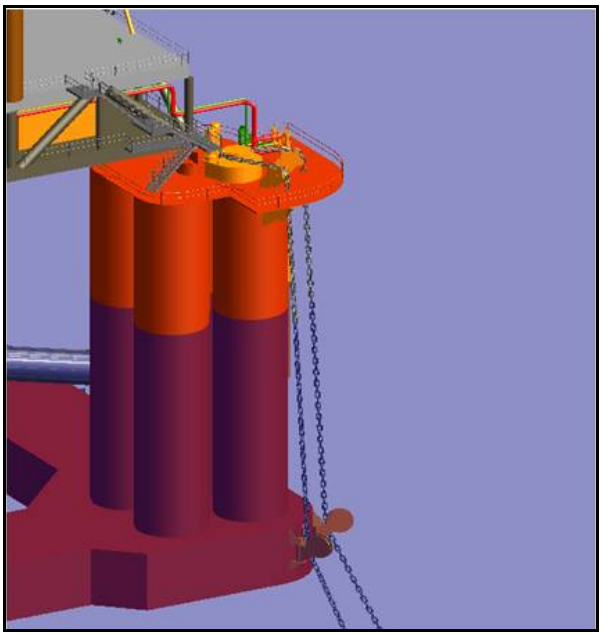


Figure 3-72. Corner Tensioning Subsystem - Two legs

A-1310 Tensioning Subsystem Risks:

The risks and mitigation methods associated with the Tensioning Subsystem are summarized in Table 3-28 below.

Table 3-28. Tensioner Subsystem - Risks and Mitigations

#	Risk	Mitigation
1	Load released due to loss of power or damage to the tensioner	This risk is mitigated by the chain stopper design which mechanically locks the chain as it is pulled in with latching dogs that are self latching and must be mechanically or hydraulically released. Thus, if all power is lost to the system, the default is the chain is locked by the chain stoppers.
2	Chain stoppers, fairleads, and/or windlasses break free from the platform during extreme conditions.	This risk is mitigated by detailed design and analysis of the platform structural interfaces and by removing the windlasses from the load path once the moorings have been installed through use of the chain stoppers.
1	Load released due to loss of power or damage to the tensioner	This risk is mitigated by the chain stopper design which mechanically locks the chain as it is pulled in with latching dogs that are self latching and must be mechanically or hydraulically released. Thus, if all power is lost to the system, the default is the chain is locked by the chain stoppers.

A-1310 Tensioning Subsystem - Forward plan/Next Steps

The next steps for the tensioners include completion of a detailed specification for the tensioner components based on the final loads analysis and rated capacity requirement. As previously discussed, the rated capacity may be increased to meet the requirements for proof load if the cost impact is not significant and is offset by the savings with this approach. Presently the nominal spec for the tensioners is significantly above the required proof load for the pilot phase and within 5% of the required proof load for the production phase.

In addition, the methodology for initial handoff of the mooring legs to the platform during installation, and subsequent routing of legs through fairleads and chain stoppers to the tensioners and chain lockers must be established. A detailed CONOPS plan for the mooring installation will include these details.

The tension members are the components in line between the anchors on the seafloor and the tensioner on the platform. For conventional moorings this normally includes chain at both the platform and anchor interfaces and wire rope or synthetic poly rope in between. In addition the required hardware for connecting the different members is included.

A1320 - Tension Members

Tension Member Requirements:

The requirements for the tension members are summarized in Table 3-29 below.

Table 3-29. Tension Member Requirements

Requirement	Source	Rationale	Impact
Mooring lines to be sized according to API criteria for steel, ABS for poly	General offshore best practices	Established specifications and requirements that are applicable to OTEC	Mooring design and sizing of components
Watch circle of platform during worst conditions will not cause damage to CWP or power cable	General best practices and method to minimize risk and potential costly damage	Avoid costly damage to power cable and cold water pipe	Scope and pretension of mooring as well as loads on mooring
Mooring for Pilot Phase to be designed for 2 year service 25 year storm	Derived Requirement	Pilot phase duration is established, design storm selected based on duration	Loads, materials, and sizes of mooring components for pilot phase
Mooring for Production Phase to be designed for 20 year service, 100 year storm	Derived Requirement	Production plant phase duration is established, design storm selected based on duration	Loads, materials, and sizes of mooring components for production phase

Requirement	Source	Rationale	Impact
Plant interface for tensioner, mooring tensioner, chain fairlead, and chain stopper to be designed for production loads	LM team derived requirements , trade study results	Eliminates costly platform and equipment retrofit after 2 year period	Tensioner size, platform interface design, chain size (since driven by tensioner), fairlead and chain stopper size

A 1320 - Tension Members - Design Trades/Approaches

There are established codes for mooring tension members in the offshore industry and these were used in sizing the mooring lines for the OTEC Pilot Plant. Depending on the selection of material for the tension members the following applicable codes will be adhered to:

Mooring Condition	Intact	Damaged
Steel Components (API)	60% BS* * Breaking Strength	80% BS
Synthetic Components (ABS)	55% MBL* * Mean Breaking Load	70% MBL

The intact load refers to the maximum dynamic load on any mooring single line with all mooring lines intact. The damaged condition refers to the maximum resulting load after one or more legs has been damaged or lost. For steel components such as wire rope and chain, the max load is based on a percentage of the Break Strength (BS) of the wire rope while for synthetic mooring lines; it is based upon a percentage of Mean Breaking Load (MBL).

The primary design trades conducted for the tension members considered:

- Tension member materials (Wire vs Polyester Rope).
- Sized and rated strength of the tension members
- Number of tension members deployed.

As discussed in the trades at the element level, the number of mooring legs has a direct impact on the strength requirements for each the tension member based on maximum loads for the intact and damaged conditions. The other study evaluated whether the initial mooring installation would cover both the Pilot Phase and the Production Phase plant loads.

The options for mooring line materials are essentially wire or polyester rope. The industry standard for permanently mooring platforms in water depths like OTEC and with 20+ year life requirements is to use spiral strand wire rope. Polyester rope moorings have recently been favored for deeper permanent installations (greater than 1600 m). Polyester is more expensive than equivalent strength wire rope but is much lighter wet weight which significantly reduces vertical loads on a platform in very deep water, and allows relatively lower cost installation vessels to be used because of the lower installation loads. Conversely wire ropes tend to require swivels due to torque characteristics and suffer from corrosion issues after prolonged

submersion. A realistic replacement interval for wire rope legs is 3-5 years which can result in high replacement costs for a 20 year system. While the baseline for the Pilot Plant -Production Phase has been using Poly rope approximately 8" in diameter to meet the strength and life requirements, the estimated loads are significantly lower for the Pilot Phase as the service life requirement is estimated to be 2 years. The reduced loads in the Pilot Phase allows for the use of much more economical mooring lines made with smaller diameter wire rope. In addition, wire rope legs used for temporary moorings may be available for lease as well as purchase. Based on preliminary quotations, however, it was determined that the costs for leasing wire rope mooring lines was approximately the same as a purchase for a two-year service period.

The other advantage for using wire rope for the Pilot Phase is that the weight of the wire rope creates a catenary in the water column even at maximum tension. This yields a very shallow pull angle on the seafloor chain and anchors which increases the performance of the anchors and eliminates the need for additional clump weights or depressor weights in the system. The tradeoff is that the mooring will need to be replaced to meet the higher load and extended life requirement for the Pilot Plant Production Phase. This will allow the technology to be tested however with a minimum initial outlay for the mooring system and once proven successful, the tension members can be upgraded as required.

For the Pilot Plant-Production Phase, the design loads are much higher and the poly has very little in-water weight, significantly decreasing the catenary effect and increasing the resulting pull angle on the anchors and chain. For this reason, it may be necessary to add clump weights to reduce or eliminate the vertical load component on the anchors during the production phase. The intention however is that the only component that will need to be changed after the initial pilot phase will be the tension members, not including the chain. As discussed in the tensioner section, the chain will be sized for the Production Phase since it keys into the tensioner during operation. The anchor and chain therefore may be left in place with the use of subsea connectors that allow the tension members to be broken and re-mated subsea, significantly reducing the loads and time required to upgrade the moorings for the production phase. The clump weights would be pre-attached to the new mooring lines and lowered along w/ the subsea connector for re-mating to the seafloor anchors. Platform mooring installation experts have been consulted regarding this operation and are confident in the ability to successfully complete it with the use of ROVs (remotely operated vehicles).

A-1320 Tension Members - System Diagrams and Graphics

Representative deepwater offshore mooring components are shown in the following Figures. Figure 3-73 shows a representative deepwater offshore polyester mooring line. Figure 3-74 shows the deployment of typical offshore mooring chain, and Figure 3-75 shows a representative deepwater mooring shackle that forms a chain/polyester rope mooring line connection.



Figure 3-73. Representative Deepwater Offshore Mooring Line (9" Whitehill Polyester Mooring Line)



Figure 3-74. 4.5" Studless Anchor Chain



Figure 3-75. Shackle - 4.5" Mooring Chain to 9" Poly Line

A-1320 Tension Members - Risks

The main risk for the tension members is associated with in-service failures. There are a number of ways to minimize this risk. The first is to adhere to the codes for offshore platforms listed at the beginning of this section. As with any codes however, they are based upon a maximum load condition which is normally derived through analysis so the analysis results must be rigorously checked and verified by model testing.

Another risk mitigation measure is to regularly inspect the mooring lines. While it is not economically feasible to do this multiple times per year, an annual visual check is recommended, and required if the mooring system is to be classed. The annual inspection is conducted with the use of an ROV to determine if any visual damage has occurred and subsequent replacement is recommended if significant. In addition, samples of the in-service tension members may be removed and failure tested over certain intervals to verify the remaining integrity of the members. This requires short lengths of test samples be included in the initial mooring assemblies and a methodology established for removing them in-situ. The chain is normally a very low risk item but should be inspected as well especially in areas of high wear and cycling such as fairleads and chain stoppers. Using the tensioner at regular intervals to change the location of these high wear spots is normally recommended as well.

An additional potential risk is the possibility of shark/fish bite. For many Navy projects, this risk has been mitigated through the use of wire rope for mooring lines, especially where loads are low and the resulting diameters are relatively small. Another risk mitigation measure is to conduct a study on the fish in the area concerned and the frequency of past fish bite incidents to determine if the threat is realistic. For platforms the size of the OTEC plant, the mooring lines is normally a large enough size that the risks of significant damage from fish bite are minimal.

There has never been a recorded fish bite incident on rope of the size required for a permanent offshore mooring of this type.

A-1320 Tension members - Forward Plan/Next Steps

The next step for the tension member design and analysis is to verify the factors of safety for both the lines for Pilot Plant - Test Phase and the Production Phase as well as all of the hardware required to connect lines to chain and chains to anchors. In addition, the procedures for using the subsea connectors will be reviewed and the required hardware mooring components tested if possible. Model tests have been proposed as part of a DOE Project. Detailed CONOPS for installation, replacement, inspection, and removal will be established as well for the tension members as well as the other mooring components.

A-1330 Seafloor Anchor Subsystem:

The seafloor anchoring system is the seafloor interface which takes out all of the mooring loads both lateral and vertical. There are various types of conventional and unconventional anchors used for offshore platforms. What should be noted about the OTEC plant is that it is in deep water, in a remote location, and the mooring components should be low-risk and economical to purchase/install to help minimize the payback period for the energy produced. This will hopefully lead to future systems based on the demonstrated economics, performance, and system availability. These points differentiate OTEC from many standard offshore platforms that look similar but have a very different payback economics.

The major uncertainty that makes anchor selection difficult is the bottom conditions which may vary over a short distance in some areas let alone different sites. For this reason, a detailed geotechnical review is normally needed prior to the selection of anchors and testing is recommended if feasible to verify bottom conditions and resulting holding power.

For the Hawaii Pearl Harbor pilot plant site considered for OTEC, surveys are in process with some partial success in determining bottom composition and sediment depth. These results are summarized in (Section 3.3.1) and Appendix 3.3-10 and will be included in a detailed survey report to be released in Q4 2010. There are still two of the proposed anchoring quadrants that require additional core samples be obtained to characterize the bottom conditions and an additional survey in late 2010 will be conducted to in an attempt to gather this information.

A1330 - Seafloor Anchor Requirements:

The seafloor anchor requirements are summarized in Table 3-30 below.

A-1330 Seafloor Anchors - Functional Block Diagram

As shown in Figure 3-76 below, the anchor type is driven by bottom conditions, the magnitude and angle of mooring loads, and installation vessel capabilities. Once the type is selected, the size and weight needed for the conditions can be calculated and the resulting anchor performance determined.

Table 3-30. Seafloor Anchor Requirements

Requirement	Source	Rationale	Impact
Anchors be installed by vessels of opportunity	Derived requirement	Reduce costs by keeping size and type of anchor able to be installed by available vessels	Reduces installation costs
Anchors suitable for seafloor conditions	Derived requirement	Optimize size and weight for conditions to reduce costs	Determines optimal anchor design for site
Anchors sized for worst case vertical and lateral loads	General offshore best practices	Assures anchors will hold platform in worst case conditions	Size and weight of anchor
Proof load drag embedment anchors to 80% of max intact load	API RP 2 SK requirement	Sets anchors and reduces risk of dragging during period of performance	Requires tensioner or other device be employed to tension each anchor as it is installed
Anchors able to retain holding power after angular offsets in pull angle due to damaged leg condition	Derived requirement	Platform must be able to survive damaged leg condition and offset must be minimized to avoid damage to power cable and/or CWP	Anchor design must be able to withstand changes in direction and either remain set or reset easily w/ minimal distance required

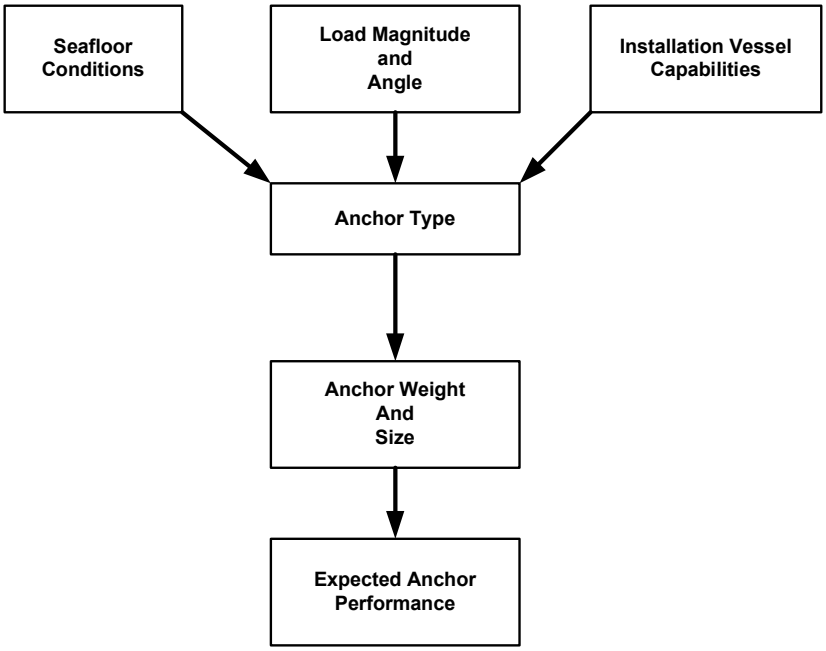


Figure 3-76. Seafloor Anchors - Function Block Diagram

A-1330 Seafloor Anchors: Anchor Design

The specific survey location off of Oahu- Pearl Harbor showing sediment core locations and potential anchor sites is shown in Figure 3-77. The coring sites were chosen to take advantage of the relatively level anchoring plateaus on each side of the 1100m OTEC site.

The performance of drag anchors is highly dependent on loads, pull angle, bottom type and stiffness, and the depth of sediment. Figure 3-78 shows a preliminary isopach chart for the candidate Pearl Harbor OTEC site. The contours shows sediment depth in meters as recorded on from the sub-bottom survey completed in the Spring of 2010. Also plotted are the locations where prior sediment coring was attempted and the candidate locations of anchors used to support the platform load analysis. Red/yellow areas show areas of relatively deep sediment while the blue/green areas show areas of shallow sediment. An additional survey cruise planned in Q4 of 2010 will attempt to secure sediment cores in coring Sites 1 and 4. The final location of anchor sites can be established after further analysis of the sediment depth data coupled with an analysis of the strength properties of the additional core samples. The quadrant with the least sediment cover is coring site 4 to the NE of the candidate site location. Anchor legs will likely need to be extended in the SE quadrant (Site 1) to ensure adequate sediment depth. Sites 2 and 3 have ample sediment depth and yielded successful cores.

The depth of embedment of anchors is directly proportional to the load on the anchors and the stiffness of the soil as will be seen in subsequent plots. In some conditions drag anchors are purposefully oversized to minimize the amount of area and the depth of sediment required to reach the required holding capacity. The strengths and depths of sediment are discussed in detail in the Appendix 3.3-10 (Anchoring and Mooring Considerations for an OTEC Pilot Plant; R. Taylor and D. True). The results of the coring obtained and the associated sub-bottom bottom profiles for these areas indicate that there is sufficient depth of sediment for drag embedment anchors to be potentially effective. Their performance depends on the strength and type of soil which is also summarized in the appendix. Analysis results for drag embedment anchors in the soils found in Sites 2 and 3 are shown in plots later in this section.

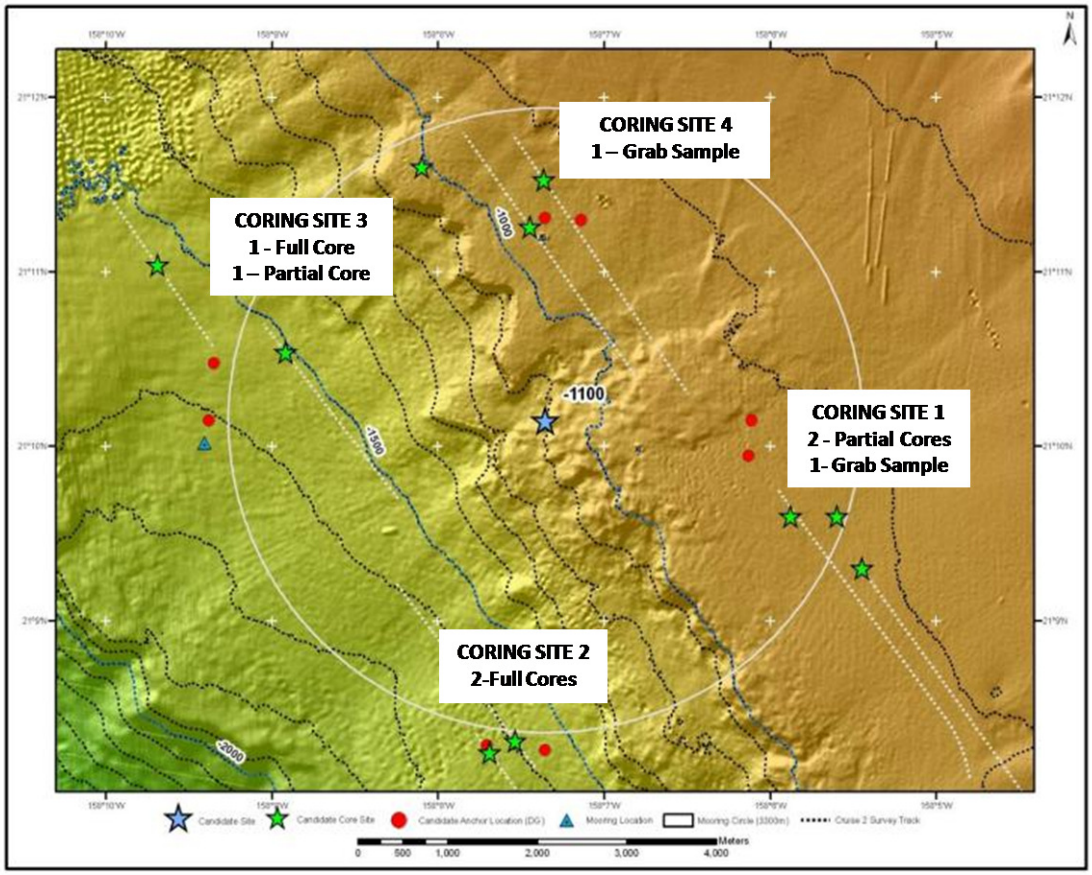


Figure 3-77. Coring Results - Potential OTEC Site - Pearl Harbor

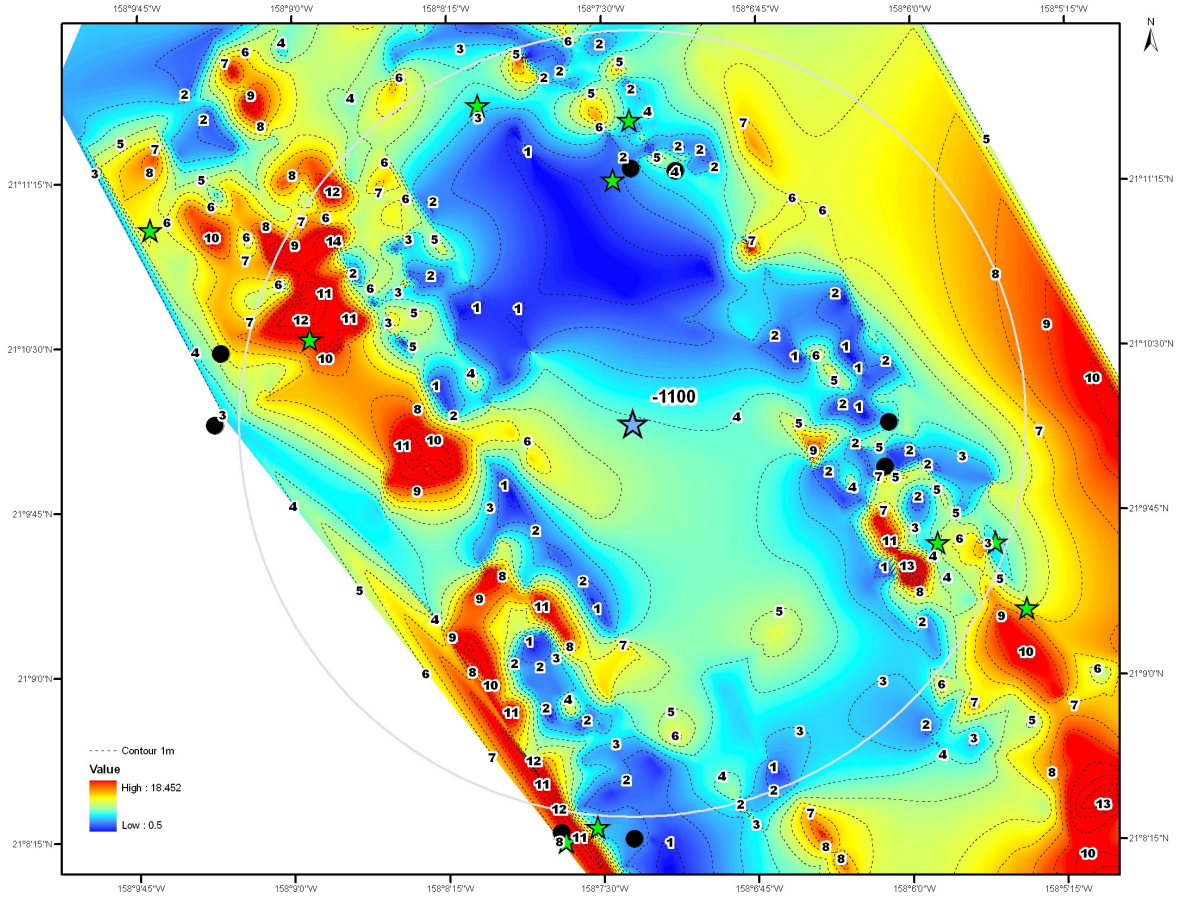


Figure 3-78. Preliminary Isopach Chart - Pearl Harbor Site

Table 3-26 provided the results of the platform mooring analysis tabulating the maximum intact and broken (1 leg broken) loads on the anchors for the mooring configurations defined for both the Pilot Plant Test and Production Phases. This included both four-line and eight-line mooring configurations and poly and wire rope line configurations.

Anchor size and weight drives the cost of both the anchors themselves and most critically the size and cost of the installation vessels. While gravity anchors are sometimes used in areas with questionable bottom sediment conditions, their size and mass of can become large enough to exceed the crane safe working load capacity for most installation vessels. A practical limit for nearly all large anchor handling vessels is a static load of 400 tons. Depending on the combined weight of the anchor, chain, and mooring lines, the maximum handling capability can be easily exceeded for large gravity type anchors.

A related consideration is the depth of water for the installation. For relatively shallow depths such as that used to moor large ships, it is possible for vessels to handle loads upwards of 400 tons as indicated above. Once these depths exceed a few hundred meters however, the potential for large loads due to platform motion and acceleration in anything but flat calm seas can often cause dynamic load factors as high as 1.5 to occur. For typical OTEC platform installation

depths (1000 m or greater), this large of load factor must be assumed, resulting in the re-rating of the allowable static load allowable load to 250 tons or less for most of the larger anchor handling style vessels. A practical consideration related to the factors above is the cost of installation. If the size of vessel and equipment are driven up by the type of anchors and/or loads during installation, the installation costs will accordingly increase. A final factor that must be considered is the available scope or angle of the mooring legs. A taut mooring will by its nature have a very high pull angle and potentially high tensions. This does not lend itself toward drag embedment anchors which prefer a shallow pull angle. A better choice would be a suction or drilled pile which are designed for high tensions and pull angles. For the OTEC platform, where a decent scope (2:1) is available for the areas considered, the pull angles can be reduced to an acceptable level for drag embedment anchors.

A-1330 Seafloor Anchors - Design Trades

A number of anchor styles were investigated for use with the OTEC Pilot Plant mooring system. These included:

- Drilled rock anchors
- Skirted clump weight anchors
- Drag embedment type anchors.

In addition, the mooring configuration trades considered:

- Anchor scope
- Number of anchors/legs per corner.

The candidate anchor configurations explored are more fully discussed in Appendix 3.3-10. The advantage of the skirted clump is that it takes very little sediment cover to set to its fullest potential. The disadvantage is that its holding capacity is driven by its mass and friction coefficient which often results in high weights and very large anchors. Given that there is enough sediment cover, the true drag embedment anchors like the Bruce FFTS MK4 anchors provide a much higher load capacity to weight ratio, reducing the installation loads considerably. The other advantage to drag embedment anchors is that they have extensive field experience and proven track record with extensive test results in a variety soil conditions.

Within the family of drag embedment anchors, such as represented by the Bruce FFTS MK4, performance tradeoffs involve fluke angle vs. size/weight of the anchor. Depending on whether the seafloor is composed of sand or cohesive clay or mud, the fluke angle may be set differently to reach its maximum potential holding capacity. In addition, the size may be increased beyond what is needed for lateral capacity to minimize the distance and depth it takes for the anchor to reach its required load capacity. This allows large drag embedment anchors to often successfully hold back loads in relatively shallow sediment cover areas where smaller anchors would dig beyond the sediment cover and fail to hold the load. For higher pull angles, both drag embedment and skirted clump anchors start losing their effectiveness in holding back lateral loads. The solution, which has been used successfully in other deepwater mooring solutions, is to add a clump weight which adds a little complexity and load to the deployment, but very effectively reduces the pull angle to a level that allows the drag anchor to maintain its holding

effectiveness for the given conditions. This is illustrated in Figure 3-79 below. Examples of the drag embedment and skirted clump anchors are shown in Figure 3-80.

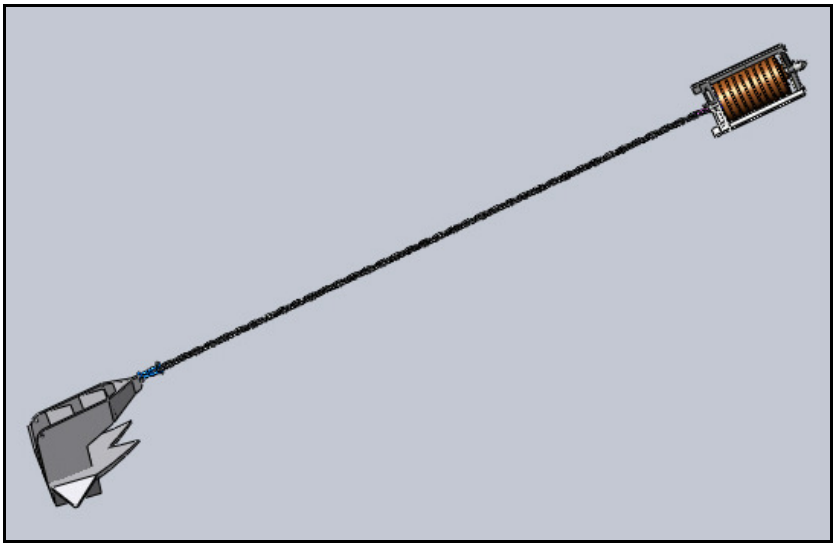


Figure 3-79. Bruce Drag Embedment Anchor with Clump Weigh to Reduce Pull Angle





Figure 3-80. Bruce Mk4 FFTS Drag Embedment Anchor (Left) and Kings Bay Skirted Clump Anchor (Right)

The plots in Figure 3-81 and Figure 3-82 show the anchor performance for various sizes of the Bruce FFTS MK4 drag embedment anchors in the soils for which cores were recovered in the OTEC Pearl Harbor survey. The plots show holding capacity versus depth of embedment for the flukes and the vertical lines show the max intact conditions for the 8-wire pilot plant and the 8 line poly production plant. The anchor that is the baseline for both pilot and production is the 40 metric ton (mT) Bruce FFTS which will allow it to be left in place after the Pilot Plant -Test Phase. Should the Pilot Plant transition to the Production Phase in situ, the anchor system can be augmented by addition of a clump weight to take out the additional vertical loads associated with

the higher 20-year environmental load conditions. As seen in the plots, the 40 mT is oversized for the Pilot Plant-Test Phase, but will be sufficient for the production loads given that sufficient sediment strength and depth is confirmed for the remaining two anchor sites.

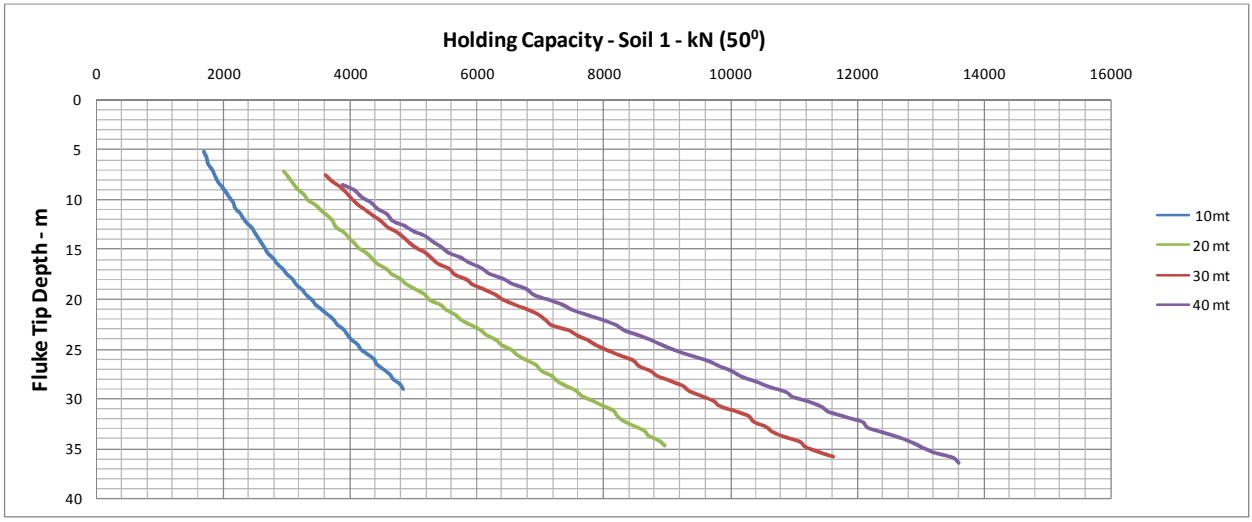


Figure 3-81. Holding Capacity vs Fluke Depth for 10-40 mT Bruce Anchors-Soil 1

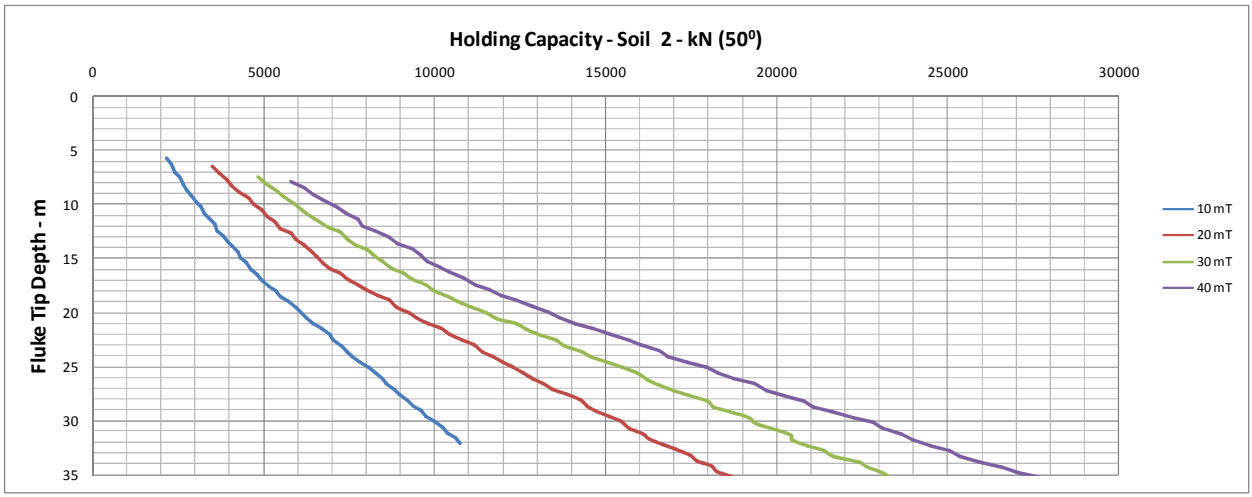


Figure 3-82. Holding Capacity vs Fluke Depth for 10- 40 mT Bruce Anchors-Soil 2

A-1330 Seafloor Anchors - Risks

The risks associated with anchors are mostly relate to the risk of anchor slippage or dragging due to poor bottom engagement, changes in angle during operations, or fouling on objects on the seafloor. The risk mitigations include:

- Conduct an adequate anchor survey so that the bottom conditions (seafloor bearing capacity, stiffness, cohesiveness, and sediment cover) are known allowing anchor sizes and configurations to be selected.

- Conduct anchor tests in the locations of interest to better validate the survey results as well as the hold back capacity of the anchors. These tests are often conducted with smaller scale anchors and load monitoring equipment which may then be used to extrapolate expected results for larger anchors.
- In deep water applications employ anchors which are easy to install, not top heavy, and not likely to foul on small objects. An example of an anchor which would not be suitable for typical deep water applications would be a tall skirted clump with the attachment eye near the top of the clump. Any off-axis pull or local steep angle could cause the anchor to topple on its side, negating its effectiveness and requiring reinstallation.
- Develop a detailed CONOPS with contingency plans and use a tracking sonar device attached to the anchor so that its location and depth may be tracked as it is lowered allowing precise touchdown in the intended area of use. For drag embedment anchors, it is normal practice to move forward slowly with the anchor handling vessel as the anchor approaches the seafloor so the chain does not pile up on top and/or foul the flukes as tension is applied.
- Include a planned proof-load test during installation so that if the required hold back load is not reached, the anchor may be recovered and reinstalled/reconfigured until the required capacity is demonstrated. This will be required by a certifying agency such as ABS.

Forward plan/Next Steps

As discussed above, an additional survey will be used to validate seafloor conditions for the remaining two anchor locations. In addition a more detailed anchor survey will be conducted in the final site location. This survey will require coring at the anchor locations to a depth at least equal to the depth of influence for the proposed anchor solution[xiii]. Once these areas are adequately characterized in terms of sediment type, stiffness, and depth of cover, the configuration for all legs of the mooring can be finalized and detailed and corresponding installation CONOPS completed.

If there is a determination that one or both of the remaining sites to be surveyed do not lend themselves toward the use of drag embedment anchors, alternative solutions will be investigated. Options such as adding an additional leg or increasing number/size of anchor per leg may be used to minimize the depth of sediment required to reach the required capacity. Other options include investigating adjoining areas for the anchors in an effort to find more suitable conditions, using hybrid designs in one or both of the locations if necessary including skirted clumps or other styles suitable for the given bottom conditions. A new seafloor drilled and grouted anchor template, under development by Lockheed Martin, may be a candidate in areas of little or no sediment cover. This would require further testing and approval by ABS prior to use on a commercial platform.

It will also be desirable to conduct a more thorough platform analysis with the wind, wave and current directions applied based on hind-cast results and the geography of the locations. The current approach is quite conservative in that it assumes the environmental loads are applied simultaneously and from the same direction. The results may indicate one or more of the anchor locations have substantially lower loads than the others due to its location in the mooring pattern. Analysis should be verified by model tests.

Once the design has been finalized for the anchors, discussions with platform mooring experts will resume in order specifying all of the components required for installation, tension member replacement, etc. in order to complete the detailed specification and design.

A-1300 - STATIONKEEPING SUMMARY

The results of the load analysis and sizing of the mooring system components are summarized for each of the defined configurations in Table 3-31 to Table 3-33. Table 3-31 summarizes the results for the Pilot Phase 4-line Wire Configuration. Table 3-32 summarizes the results for the Pilot Phase 8-line wire rope configuration. Table 3-33 summarizes the results for the Production Phase 8-line polyester rope configuration. It should be noted that the margin of safety incorporates the factor of safety so that anything zero or above is considered acceptable.

Table 3-31. Pilot Phase - 4 Line Wire Rope Configuration

ELEMENT	QTY	SIZE	TYPE	LOAD CAPACITY	FACTOR OF SAFETY	MARGIN OF SAFETY
CHAIN	4X 1000 m 4X 2000 m	3” (76.2mm)	R4	1045 kips	1.67 intact 1.25 damaged	.08
WIRE ROPE	1 x 2063 m 1 x 3770 m 1 x 3835 m 1 x 2075 m	3.25” (82.6 mm)	GALV EIPS 6X36 IWRC	984 kips	1.67 intact 1.25 damaged	.08
TENSIONING SYSTEM A	4	3” (76.2mm)	Linear Chain Jacks	295 kips min	1.25	Depends on actual design
TENSIONING SYSTEM B	4	3” (76.2mm)	Windlass	295 kips min	1.25	Depends on actual design
SUBSEA LATCH	4	3” (76.2mm)	Latching fairlead	1150 kips min	1.1	Depends on actual design
ANCHORS	4	20 mT	Bruce FFTS MK4	600 tonne	1.5	0.74

Table 3-32. Pilot Phase - 8 Line Wire Rope Configuration

ELEMENT	QTY	SIZE	TYPE	LOAD CAPACITY	FACTOR OF SAFETY	MARGIN OF SAFETY
CHAIN	8X 1000 m 8X 2000 m	4-1/8” (104.8 mm) *Alt. 4 ½”* *(114.3 mm)*	R5 R4	2372 kips	1.67 intact 1.25 damaged	2.6
WIRE ROPE	2 x 2063 m 2 x 3770 m 2 x 3835 m 2 x 2075 m	2. 5” (63.5 mm)	GALV EEIPS 6X19 WIRE ROPE	664 kips	1.67 intact 1.25 damaged	0
TENSIONING SYSTEM A	8	4-1/8” (104.8 mm)	Linear Chain Jacks	295 kips min	1.25	Depends on actual design
TENSIONING SYSTEM B	4	4-1/8” (104.8 mm)	Windlass	800 kips	1.25	1.74

ELEMENT	QTY	SIZE	TYPE	LOAD CAPACITY	FACTOR OF SAFETY	MARGIN OF SAFETY
SUBSEA LATCH	8	4-1/8" (104.8 mm)	Latching fairlead	2600 kips min	1.1	Depends on actual design
ANCHORS	8	40 mT	Bruce FFTS MK4	600 mT	1.5	1.45

Table 3-33. Production Phase - Eight Line Polyester Rope Configuration

ELEMENT	QTY	SIZE	TYPE	LOAD CAPACITY	FACTOR OF SAFETY	MARGIN OF SAFETY
CHAIN	8X 1000 m 8X 2000 m	4-1/8" (104.8 mm) *Alt. 4 ½" (114.3 mm)*	R5 R4	2372 kips	1.67 intact 1.25 damaged	.03
POLY ROPE	2 x 1940 m 2 x 3430 m 2 x 3450 m 2 x 1956 m	2. 5" (63.5 mm)	POLY ROPE	2600 kips	1.67 intact 1.25 damaged	0
TENSIONING SYSTEM A	8	4-1/8" (104.8 mm)	Linear Chain Jacks	295 kips min	1.25	Depends on actual design
TENSIONING SYSTEM B	4	4-1/8" (104.8 mm)	Windlass	800 kips	1.25	0.96
SUBSEA LATCH	8	4-1/8" (104.8 mm)	Latching fairlead	2600 kips min	1.1	Depends on actual design
ANCHORS	8	40 mT	Bruce FFTS MK4	2700 kips	1.5	0.1

A-1300 Stationkeeping Element - Summary

A comprehensive set of analyses, design configurations, and trade studies have been conducted to determine a preliminary baseline design for the Stationkeeping Element of the OTEC Pilot Plant. While the results are site specific, the approach will be similar for any location and can be modified as needed to accommodate different bathymetry, currents, waves, etc. The overall recommendation is that an eight-line mooring configuration should be used for both the Pilot and Production Phases as shown in Figure 3-83.

A summary of the specific recommended baselines for the Pilot and Production Phases are:

Pilot Phase - Two year Test/Demonstration

The recommended mooring configuration consists of an eight line wire rope mooring spread comprised of 2 wire-rope legs per corner. Refer to Figure 3-84. Each leg consists of:

- A vertical axis windlass tensioner rated for the production plant loads
- Each tension member is comprised of:
  - 200 m of R5 or 4-1/8" studless link chain rated for production phase loads at tensioner followed by

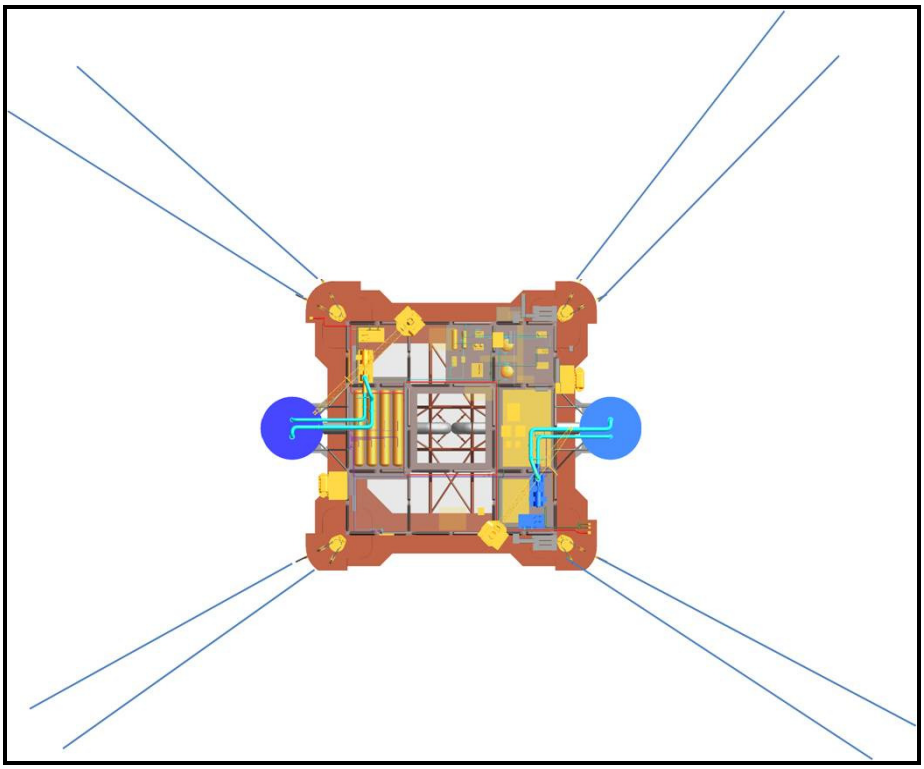


Figure 3-83. Eight Line Mooring Spread

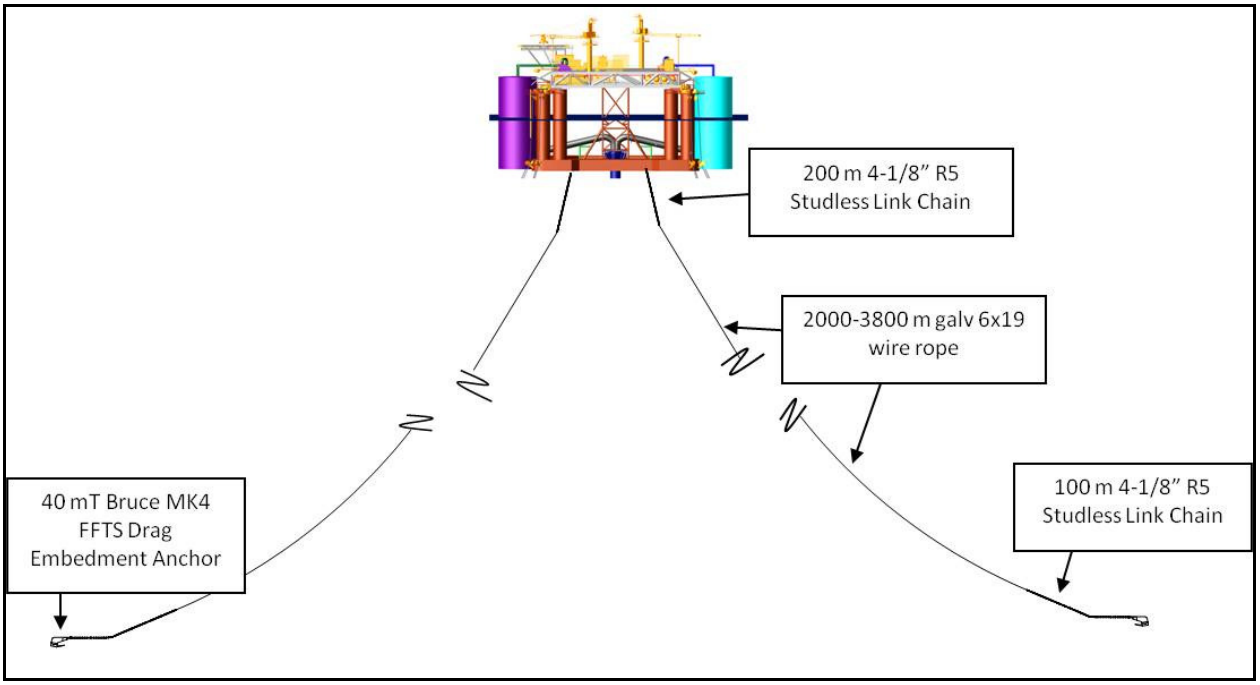


Figure 3-84. Pilot Phase - Wire Rope Mooring Configuration

  - 2000 m (shallow legs) and 3500 m (deep legs) x 2-1/2" EEIPS galvanized wire rope
  - 100m of R5 4-1/8" studless link chain at seafloor anchor
- 40 mT Bruce FFTS MK4 anchor

Pilot Plant - 20 Year Production Phase

The recommended baseline mooring consists of an eight-line mooring spread consisting of 2 polyester-rope legs per corner. Refer to Figure 3-85. Each leg consists of:

- A vertical axis windlass tensioner rated for the production plant loads
- The tension member is as follows:
  - 200 m of R5 4-1/8"studless link chain rated for production phase loads at tensioner followed by
  - 2000 m (shallow legs) and 3500 m (deep legs) x 8" Poly rope
  - 100m of R5 4-1/8" studless link chain at seafloor anchor
- 40 mT Bruce FFTS MK4

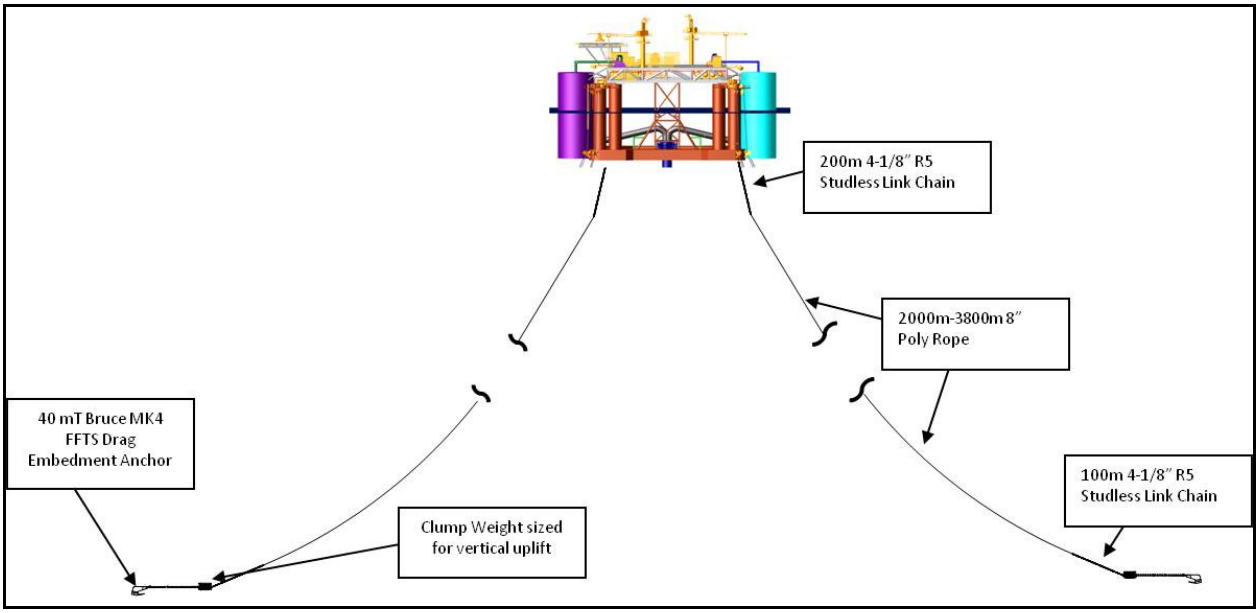


Figure 3-85. Production Phase - Polyester Rope Configuration

3.3.2 Power Generation Segment (A2000)

3.3.2.1 Power Cycle (A2100)

Power Cycle consists of the warm seawater system to boil the working fluid, the cold seawater system to condense the working fluid, the working fluid system, and the hull system which connects these three systems to the platform and provides the required buoyancy. The remora team consisted of engineers and naval architects from Lockheed Martin, Navatek, Makai, and E3Tec, with input from Houston Offshore Engineering and Horton Wison Deepwater.

Table 3-34 lists the nine key requirements of the Power Cycle Element, but other requirements total more than twenty. They are discussed below.

Table 3-34. Selected key requirements for Power Generation Segment

Requirement	Source	Rationale	Impact
Steel "Remora" removable for shipyard overhaul during 20 yr design life	OTEC04052010-RemoraReqt-PG	Not disturb CWP, Cable, moorings. Replace heat exchangers (Hx) in shipyard.	Many
Warm Water (WW) intake screen velocity < 0.15m/sec	NOAA / Environmental Protection Agency (EPA)	Environmental Impact and Permitting	Large WW intake screen
WW: 27.6° 25.7° 23.1° C CW: 3.86° 4.11° 4.35° C	HOTS (Hawaii Ocean Time-Series Study) 1 data, Makai Ocean Eng. 3 Dec 2009	HOTS 1 data is nearest to selected site.	HX size, seawater flows, seasonal power
Discharges: Prevent algal bloom or re-ingestion	Remora Reqt & NOAA/EPA	Environmental Impact , efficiency	Length and weight of hull, Mixed discharges.
Ammonia system to meet Refrigerant industry code	ASME B31.5 Refrigerant Piping & Heat Transfer, others	Safety, reliability. Cooler than B31.1 assumes	Many. Max pressure, weight.
Turbine-Gen & Ammonia storage on platform	OTEC04052010-RemoraReqt-PG	Maintainability & electrical connection	Reduces remora size & complexity
Swap seawater & ammonia pumps at sea	OTEC04052010-RemoraReqt-PG	Reliability & cost savings	Decreased downtime.

Requirement	Source	Rationale	Impact
Heat exchangers are submerged & inspectable	OTEC04052010-RemoraReqt-PG	Much lower differential pressure across HX-duct connection	Much less flooding risk. NH3 sys. Non-standard.
"Commercial" concept	OTEC04052010-RemoraReqt-PG	General layout looks like larger remora	Large efficient ducts

The first key requirement is that the assembly be mounted in a steel "remora" that is capable of being attached or detached for shipyard overhaul. This feature means that the platform and cold water pipe can remain moored offshore while periodic maintenance is done elsewhere on a portion of the commercial size OTEC systems. Construction from steel was specified because steel is the lowest cost material for platform or ship construction. The Remora Requirement document referenced here (Appendix 3.3-11) contained twenty requirements, most of which are omitted from this table of key requirements.

The next two key requirements are externally imposed values which influence the design. The warm water inlet velocity maximum speed of 0.15 m/s is expected to be imposed by NOAA based upon similar EPA requirements. These low velocities minimize environmental impacts of impingement and entrainment of small sea life, and impact the design by needing large intake screen areas and inlet ducts. Most of the older OTEC concept designs have significantly smaller intake screens with correspondingly higher inlet velocities. These older designs would probably not be approved for permits to operate. Note that NOAA has not yet definitively approved any specific intake velocity.

The warm seawater temperature, and seasonal variations, are imposed by the climate at the plant's location, and of course have major effects upon the seawater flows required and the size of installed heat exchangers. The annual average values, shown in bold in the table, were used for optimization and determination of the average net power. The maximum values shown are one standard deviation warmer than mean summer data and governs the maximum rating of the generator, switchgear and working fluid system. The minimum temperatures shown are two standard deviations colder than mean winter data and govern the minimum operating condition for the turbine.

The fourth key requirement is based upon the interaction of the seawater temperatures and currents acting upon the plant's discharge plume. The two issues to be solved are preventing the cooled warm water from being "re-ingested" into the warm water intake, which lowers efficiency, and discharging the nutrient-rich deep water below the euphotic zone to prevent an algae bloom (opinions differ on the desirability of such open-ocean blooms). Makai modeled the thermal and nutrient enrichment effect of the remora design at the NAVFAC's Barbers Point site, using a new model for OTEC plumes developed with CEROS' funding. Because of the small plant size, this plume is barely discernible beyond 440meters distance from the plant. No untoward effects from the plume are expected. A thirteen-page memo describing this state-of-the-art modeling work is provided in Appendix 3.3-12.

The fifth requirement of "ASME B31.5 refrigeration system code" means that we are using a well-established industry code for details of the ammonia system. However, it should be noted that we did not use ASME B31.1, which is applicable for power piping. This decision was based upon OTEC using temperatures and working fluids more commonly encountered for refrigeration rather than power generation.

The requirement for the turbine generator to be on the platform allows turbine and generator maintenance to be conducted in a space that can be ventilated and easily accessed. This simplified the remora layout.

The requirement to change ammonia pumps and seawater pumps while at sea flows from the assumption that rotating machinery requires more periodic maintenance or repair than static equipment such as piping and valves. By changing this equipment while the remora remains attached to the platform, operating costs would be lower and plant availability would be higher than if the remora needed to be brought to shore.

The requirement that the heat exchangers be submerged means that the seawater duct / heat exchanger interface can be simple (a gasket) because it is subject to very small differential pressures, with minimal risk if it were to leak slightly. If the heat exchangers instead were in a dry machinery space, then the interface is between the vessel / heat exchanger / seawater duct, expected differential pressures would be higher, and leaks would affect the vessels buoyancy.

The final requirement stated the project's goal that the development work give experience and hence confidence towards future commercial systems. A related effect was that since the pilot plant should make net power, then the seawater ducts and ammonia piping should be sized and arranged for optimum hydraulic efficiency instead of lowest first cost.

3.3.2.1.1 Hull Subsystem

Introduction

The hull subsystem, also called the remora, is a self-contained, detachable module that is attached to the platform and incorporates the OTEC power generation system. The "remora" or "side spar" concept was developed by Makai Ocean Engineering during Office of Naval Research (ONR) sponsored research in 2005/2006. It is comprised of the following components: Structure, cold water system, warm water system and ammonia system, with ancillary support systems, including auxiliary hull systems, electronics and instrumentation. The platform is designed to accommodate two remoras, each designed to produce a net power of 5 Megawatts electrical (MWe). Drawings of the remoras are listed in Figure 3-86. and can be found in Appendix 3.3-13 as 11" x 17" pull-out diagrams.

Figure 3-87 shows major components and interfaces of the remora hull. These consist of the mounting brackets, Cold Water connection, the buoyant hull, truss and soft tank.

A summary of remora hull key design requirements is presented in Table 3-35. A summary of the key trade-off studies is presented in Table 3-36.

Drawing Sheet Title	Number
Electrical routing Plan & Elevation	RE-1
Remora Profile	RG-1
Remora Sections	RG-2
Piping and Instrumentation Diagram	RG-3
Remora Structure and Buoyancy	RH-1
Remora Structural Arrangement	RH-2
Remora Structural Scantlings	RH-3
Heat Exchanger Foundations	RH-4
Remora Bilge/Ballast Systems	RH-5
Remora upending Conops	RH-6
Remora Towing & Docking Conops	RH-7
Remora Mating / demating Conops	RH-8
Platform/Remora Mounting Bracket	RH-9
Remora Corrosion protection	RH-10
Seawater Duct Arrangement	RS-1
Seawater pump Mounting	RS-4
Cold Water Duct Interface	RS-5
Seawater (warm) Intake screen Detail	RS-6
Evaporator	RP-10
Condenser	RP-11

Figure 3-86. List of Remora Design Diagrams

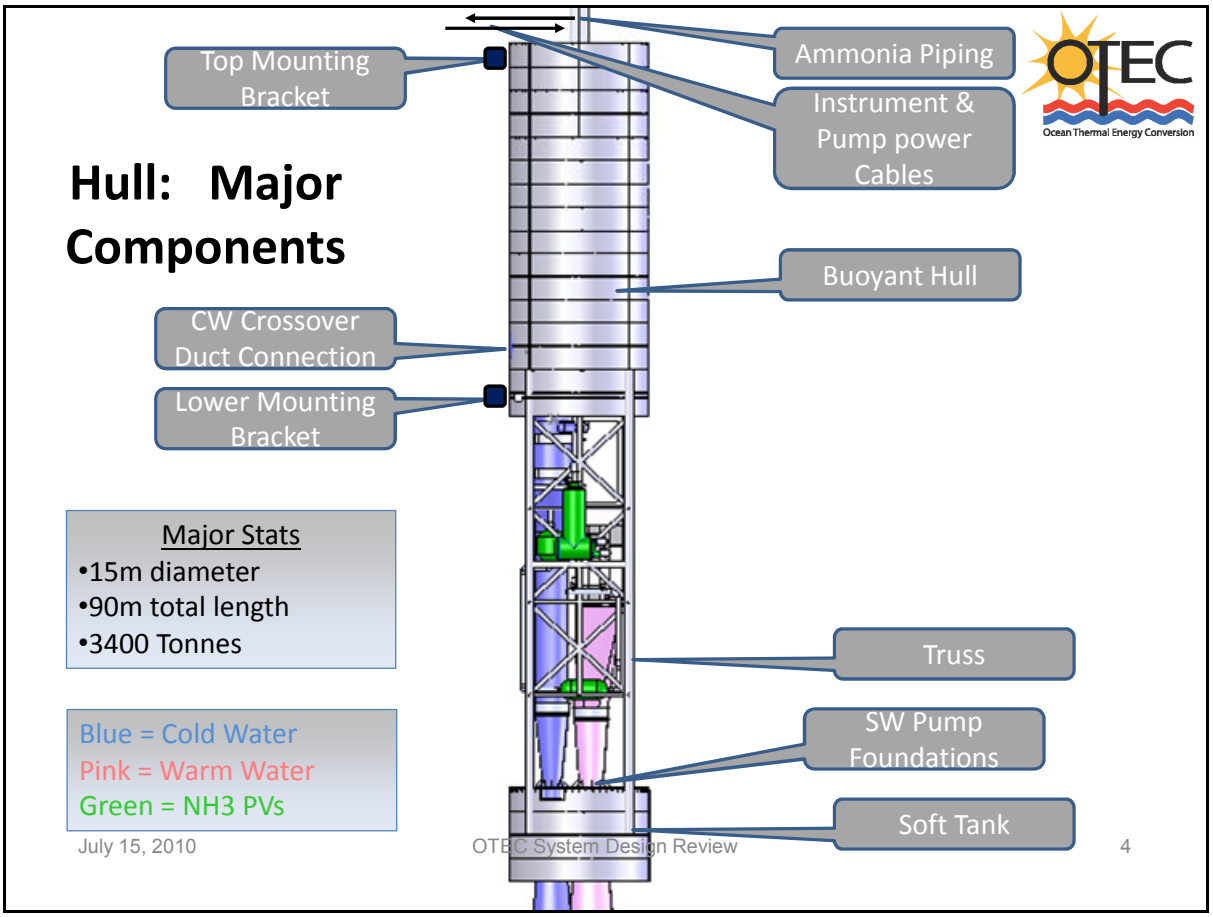


Figure 3-87. Major Remora Hull Components

3.3.2.1.1.1 Hull Subsystem

Table 3-35. Key Design Requirements

Requirement	Source	Rationale	Impact
Transportability & Platform Mating Capable of being installed after the platform has been moored and detached for periodic maintenance	Top Level Requirement	Self-contained power producing component that can be detached for more frequent maintenance and component replacement and allows multiple power-producing units to be installed on the platform	• Self-contained unit • Stable in both transit (horizontal) and deployed (vertical) configurations • CONOPS for mating and demating with the platform • Environmental constraints for mating and demating • Additional systems for mating and demating
Structure To be designed using standard offshore marine practice for a 20-year operational life off the coast of Oahu, Hawaii	Top Level Requirement	Sound, affordable structure capable of operating for an extended life in a wide range of environmental conditions	• Selection of structural materials and member sizing • Determination of structural loads • Control of structural weight
Construction Capable of construction and multiple dry-dockings in Hawaiian shipyards	Top Level Requirement	Efficient removal, repair and/or replacement of remoras using local facilities and labor	• Limits on overall remora size • Incorporation of ballast tanks • Heavy lift crane required
Stability Must meet offshore stability standards in both transit (horizontal) and deployed (vertical) configurations	Top Level Requirement	Safe and reliable transport, upending and mating of the remora to the platform with minimal risk to the remora and platform	• Subdivision of structure into watertight compartments • Inclusion of both a hard tank and a soft tank

Requirement	Source	Rationale	Impact
Auxiliary Systems Must include auxiliary systems required for operational and personnel safety	Top Level Requirement	Good marine practice with reduced manpower to preserve and protect the remora for an extended operational life	• Means to add and eliminate bilge and ballast water • Provision of means for accessing all hard tank compartments
Corrosion Minimize corrosion of multiple metallic materials in the presence of seawater for extended operational life	Top Level Requirement	Good marine practice to protect the integrity of the structure and other metallic components and to minimize maintenance for extended operational life	• Cathodic protection required • Corrosion monitoring • Additional structural and system weight

Table 3-36. Key Design Trade-Offs

Design Trades	Results and Rationale
Platform Mating	• Structural and dynamic loads between remora and platform estimated-very high loads • Alternative means of coupling between remora and platform examined-"gate latch" method at bottom of platform, sliding connection at platform deck level • Mating of both structure and cold water pipe-development of CONOPS

Design Trades	Results and Rationale
Structure	• Structure designed to ABS Floating Production Installations (FPI) and Mobile Offshore Drilling Unit (MODU) Rules-Established baseline structure for starting point • Determination of structural loads-Structural loads determined from sea state date at OTEC site used to validate baseline structure • Structure reviewed by Houston Offshore Engineering-Baseline structure reviewed and then optimized by HOE to reduce structural weight and improve constructability • Structural weight and CG estimates-Structural weight and CG monitored throughout design • Structural analysis-FEA using structural loads validated structural design
Construction	• Configuration trade-offs-Remora can be built and accommodated in Pacific Shipyard Incorporated (PSI) drydock with use of a large floating crane. Remora can also be accommodated in Pearl Harbor Shipyard drydock #4 • Drydocking CONOPS developed-In order to maintain proper draft and trim in horizontal configuration, ballast tanks need to be flooded in a prescribed order
Stability	• Monitoring of weight, CG and center of buoyancy (CB)-Remora can float in a stable condition in both the horizontal and vertical configurations • Motions analysis-Remora motions when in vertical configuration most significant in long period seas (swells). Sea state must be low and monitored carefully prior to and during mating with the platform.

Design Trades	Results and Rationale
Auxiliary Systems	• No permanently manned spaces-Watertight spaces to be sealed and tight. No ventilation system provided. • Personnel access to all watertight spaces for inspection purposes-Hatches and ladders provided. Spaces must be gas-freed before access by personnel. • Means for removal of ballast and bilge water required-Portable bilge pump and deployment tubes required for each watertight compartment in hard tank. • No permanently installed fire-fighting systems required-Portable fire-fighting equipment must be available on platform.
Corrosion	• Trade study to compare impressed current system with sacrificial anodes (I'm guessing here)-Sacrificial anode system recommended. • Multiple metallic materials in seawater require a substantial cathodic protection system. • Contact between dissimilar metals must be minimized or eliminated.

Design Iterations

An initial remora design study was conducted in 2008 that resulted in the early stage design of two remora configurations: one that incorporated the cold water system; and one that incorporated the warm water system. This more recent remora design study built on the 2008 remora design but examined a remora that combined both the cold water and warm water systems in a single body. The reasons for combining the two water systems into a single remora include:

- Reducing structural cost by reducing the structural material required. (One 15m remora requires less material than two 9m remoras);
- Reducing the ammonia system cost by reducing the amount of ammonia piping;
- Increasing the power generation efficiency by minimizing the possibility of cross-flow between the cold and warm water systems;
- Reducing environmental effects by mixing the discharges from the cold and warm water systems.

In the present study, the remora configuration evolved as various trade-offs were evaluated and design decisions made. Remora iterations examined, as shown in Figure 3-88, include Iteration 0, Iteration 1, Iteration 2 and the final Iteration 2.1.

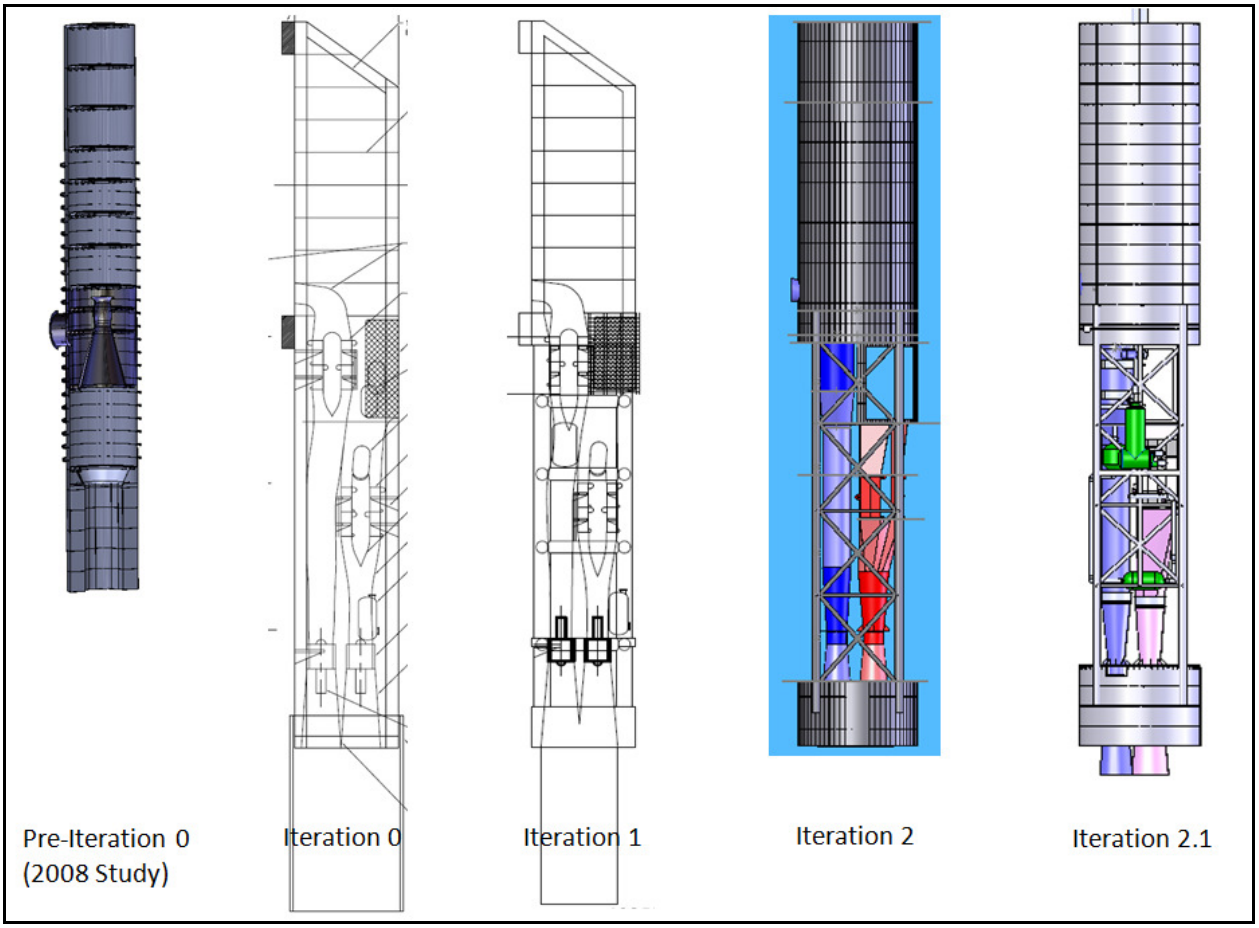


Figure 3-88. Remora Iterations Investigated

As shown in Figure 3-88. Pre-Iteration 0 (from the 2008 remora design study) is a remora with a 9m diameter structure that incorporates either the cold water system or the warm water system. The two 2008 remoras (cold water and warm water) are not identical, thus requiring two somewhat different remora configurations. The Iteration 0 remora is a 15m square-sectioned structure. Iteration 1 is a 15m diameter remora with a sloping top. Iteration 2 is a 15m circular-sectioned structure. Iteration 2.1, the final remora configuration, is a 15m diameter remora that incorporates both the cold and warm water systems and a structural arrangement considerably different than that originally designed for Iteration 2. A summary of geometry of the various remora iterations is presented in Table 3-37. The changes in weights, particularly between Iterations 2 and 2.1 reflect improving accuracy in weight estimating and the estimation of more system components.

Table 3-37. Summary of Remora Configurations

	Pre-Iteration 0 (2008 Study)	Iteration 0	Iteration 1	Iteration 2	Iteration 2.1
Configuration	Full Enclosed Spar	Full Enclosed Spar	Spar Truss	Spar Truss	Spar Truss
Section	9m Dia Circular	15m Square	15m Dia Circular	15m Dia Circular	15m Dia Circular
Seawater System	Warm or Cold	Warm & Cold	Warm & Cold	Warm & Cold	Warm & Cold
Length of Structure, Overall (m)	69.2	90	90	90	90
Approx Weight of Structure (mt)	728 (warm) 772 (cold)	2723	2241	1710	1822
Approx Total System Weight, excluding water (mt)	1196 (warm) 1256 (cold)	4315	3447	3057	3388

In addition to the trade-off study results listed previously concerning the 2008 remora design study, some of the results of the various configuration trade-off studies include:

- A square-section structure was significantly heavier than a circular-sectioned structure;
- A square-section structure resulted in a deeper draft while the remora is in a horizontal position because the remora rotates in the water until a corner is down, resulting in significant dry dock draft limitations;
- The sloping top of Iteration 2 was originally included to reduce structural weight, however it was discovered that, in fact, minimal, if any structural weight was saved and the sloping top greatly complicated the remora arrangements;
- A truss spar is not uncommon in offshore structures;
- A truss center section resulted in significant structural weight savings and permits better access to the water systems sited within the truss.

The discussion that follows for the remainder of this section is a detailed description of the design, details and trade-off studies for Iteration 2.1 of the remora.

General Arrangement

A general arrangement for the remora, Iteration 2.1, is presented in Figure 3-89 (Drawing RG-1) and Figure 3-90 (Drawing RG-2). These drawings are included in 11" x 17" format in Appendix 3.3-13. Screen shots of the 3D model of Iteration 2.1 are presented in Figure 3-91.

As shown in the general arrangement, Iteration 2.1 of the remora is comprised of three basic sections: the upper tank, also called the hard tank; the middle truss section; and the lower tank, also called the soft tank. The waterline at full load displacement, in the vertical orientation, is located at frame 17.

The hard tank has a 2.5m center tube and is divided into five longitudinal watertight compartments. Each longitudinal compartment is further subdivided into four watertight compartments. The two compartments centered at frame 2.5 and frame 7.5 can be flooded when the remora is in its horizontal orientation. The compartment between frames 30 and 40 is a

ballast tank which must be flooded in part when the remora is in its vertical, deployed orientation. This upper hull ballast tank provides the remora with draft control. The cold water intake ducting shown in the inboard profile is integrated with the hard tank structure.

The truss is fully submerged and is comprised of vertical, horizontal, diagonal and vertical support tubes through the diagonals. The truss also serves as the foundation for the major seawater system components such as heat exchangers and pumps.

The soft tank is partially flooded when the remora is in the horizontal orientation and fully submerged when the remora is in its vertical orientation. The cold and warm water discharge ducting is integrated with the soft tank structure. The soft tank is subdivided by a deck at frame 85 and further subdivided by the seawater discharge ducting.

Access to the hard tank and bilge/ballast tubes are provided on the top of the hard tank.

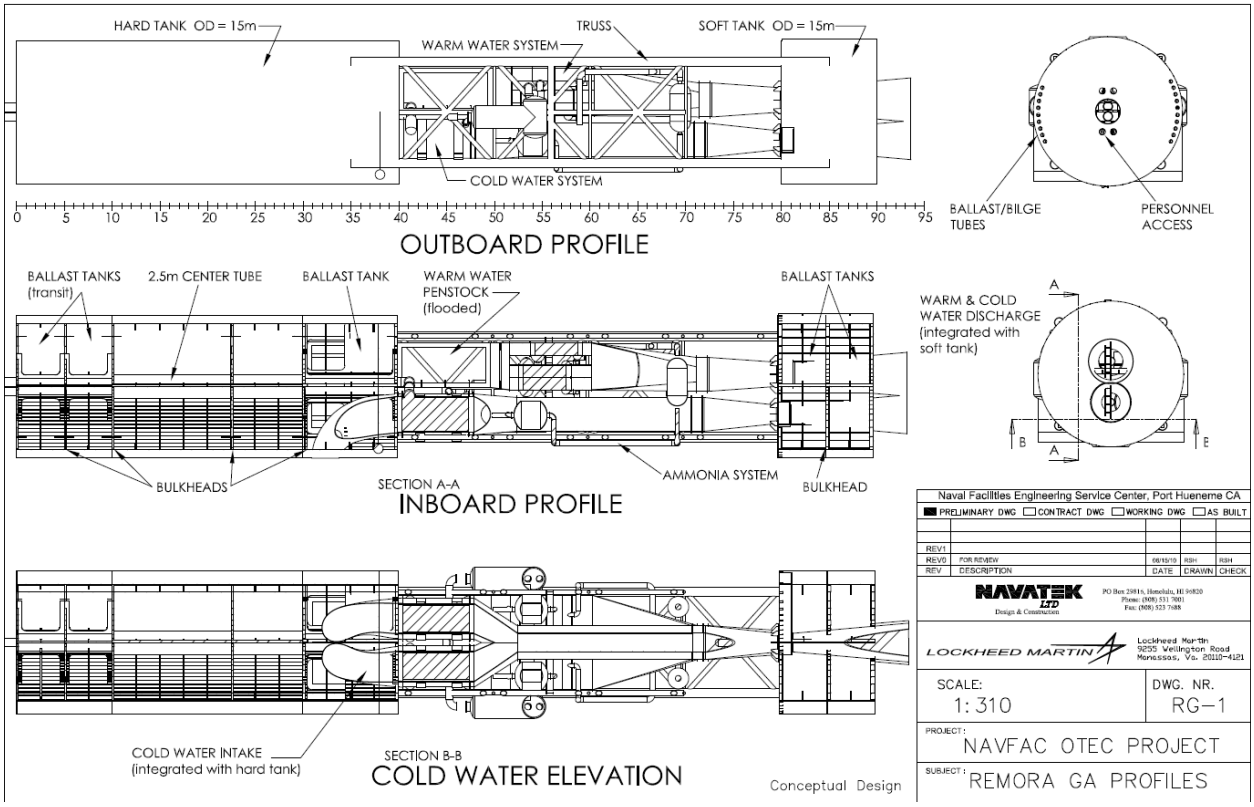


Figure 3-89. General Arrangement of Iteration 2.1 -Profiles

A more detailed discussion of the remora structure is presented in Section 3.3.2.1.1.1. A more detailed discussion of the auxiliary systems is presented in Section 3.3.2.1.1.2.

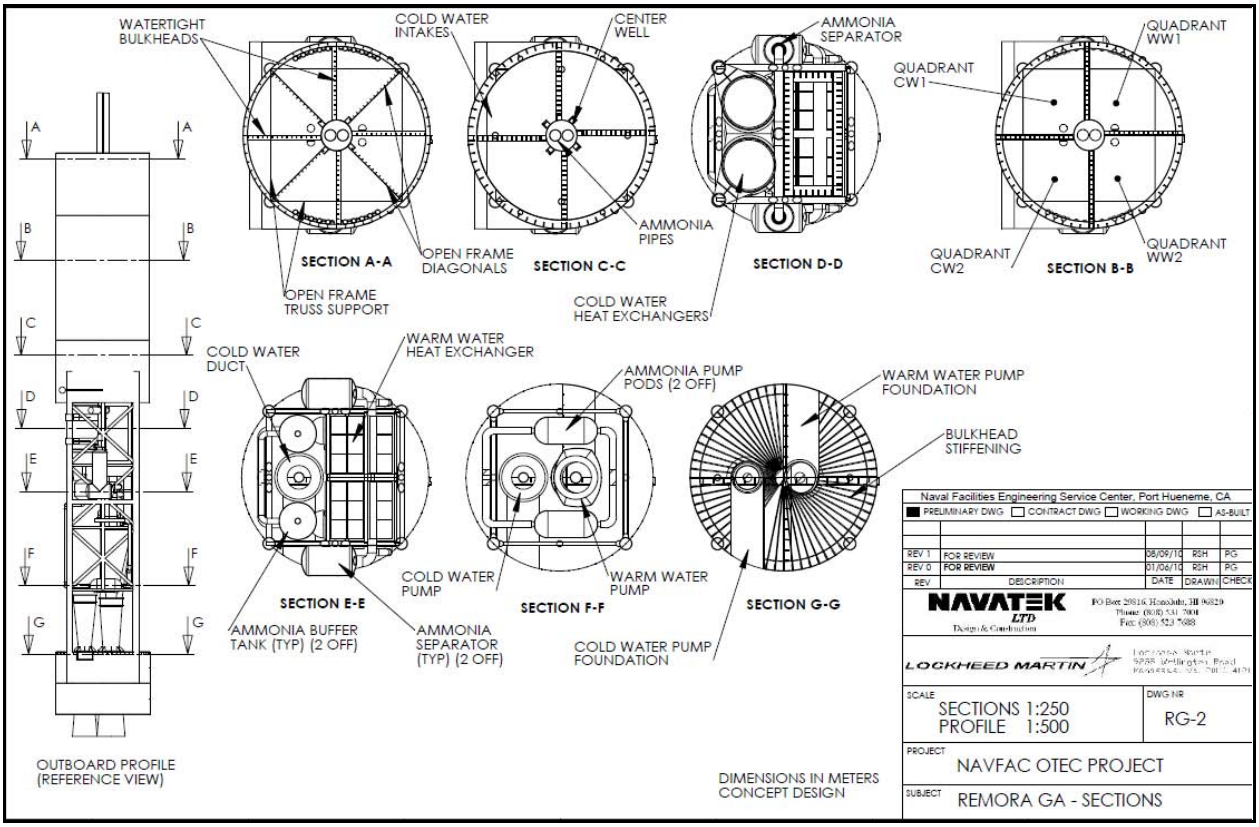


Figure 3-90. General Arrangement of Iteration 2.1 -Sections

In Figure 3-91 the color coding scheme of the three-dimensional (3d) model is: structure in gray; cold water system in blue; warm water system in pink; and the ammonia system in green. This figure shows the primary ammonia tubes coming through the hard tank in its center tube. The cold water system is located on the platform side of the remora and the warm water system is on the outboard side.

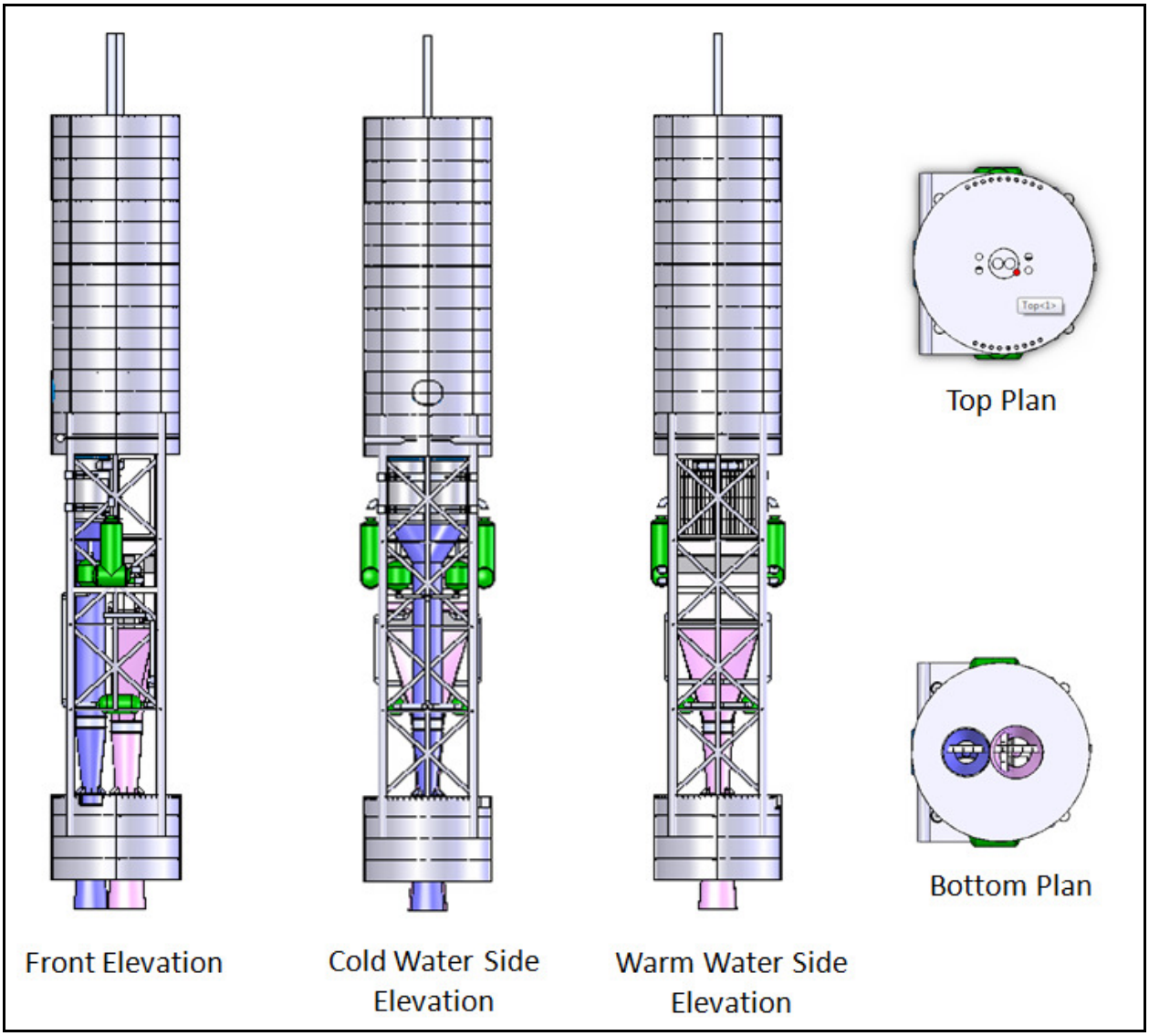


Figure 3-91. Views of Remora Iteration 2.1 3d Model

A general arrangement of the cold and warm seawater systems is presented in Figure 3-92 (Drawing RS-1). The cold water system is comprised of an intake which connects the system with the cold water pipe on the platform, two condensers and a seawater pump. The warm water system is comprised of the warm water penstock, two evaporators and a seawater pump. More detailed descriptions of the warm and cold water ducting systems are presented in Sections 3.3.2.1.3.2 and 3.3.2.1.4.2, respectively.

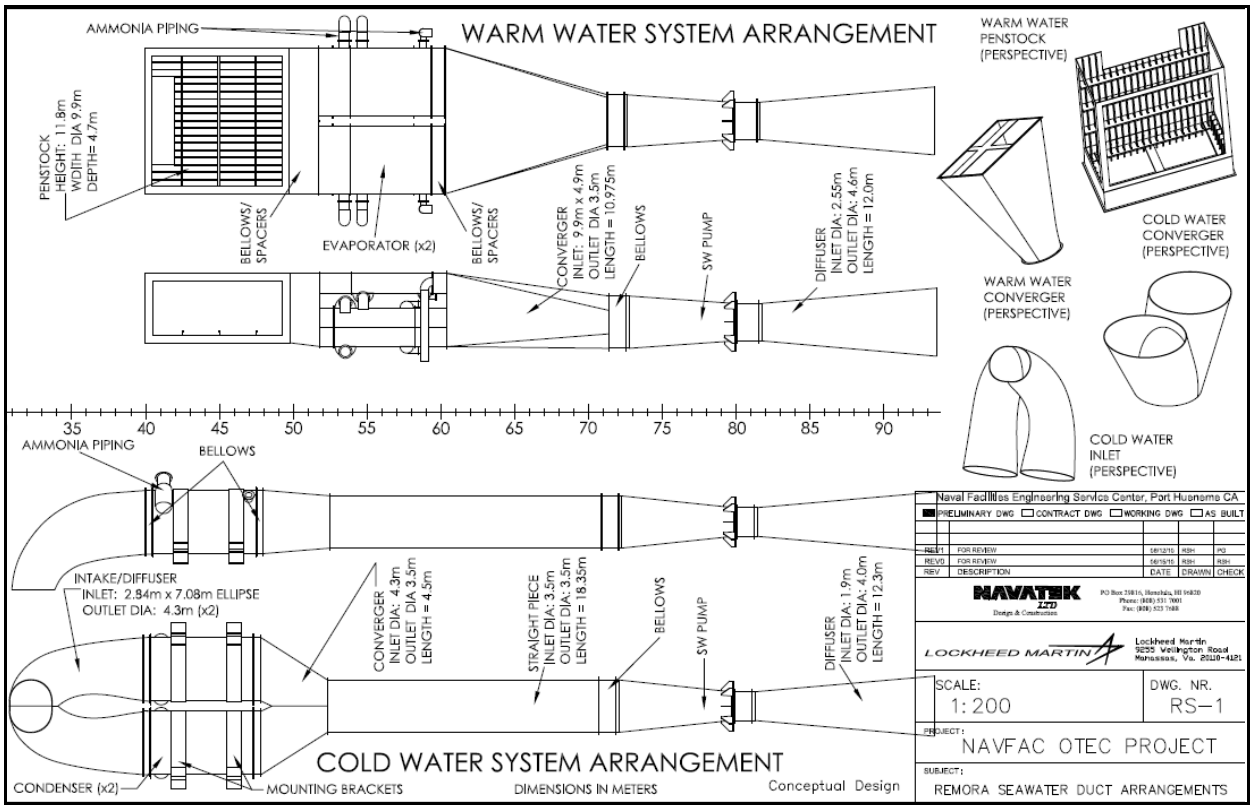


Figure 3-92. General Arrangement of Iteration 2.1 Seawater Systems

Weight and Center of Gravity

A summary of the weight of the remora, Iteration 2.1, in its vertical orientation is presented in Table 3-38. A detailed weight report for the remora in its deployed condition is included in Appendix 3.3-14. The remora weight reports have been organized using the Navy's Ship Work Breakdown Schedule (SWBS). The vast majority of the remora weights fall into SWBS Group 1 (Structures) and Group 5 (Auxiliary Systems), though there are some weights such as cathodic protection that belong to Group 6 (Outfit & Furnishings). There may be some very minor weights, such as navigation lights, etc., that belong in Group 4 (Command, Control and Communications), but these very small weights have not been accounted for.

In Table 3-38, the weight summary has been organized to show the remora's weight without water (lightship weight) and its full load weight, including water. In its vertical orientation, water is included in the form of ballast water in the hard tank and the soft tank and working seawater in the cold and warm water systems (auxiliary system water).

The center of gravity (CG) location for the remora in its vertical, deployed, configuration is summarized in

Table 3-39. In this table, the longitudinal center of gravity (LCG) is defined as its distance from the top of the hard tank; the vertical center of gravity (VCG) is defined as its distance from the edge of the remora closest to the platform in its inboard profile view; and the transverse center of

gravity (TCG) is defined as its distance from the remora centerline, with positive TCG out of the paper and negative TCG into the paper. The CG of the remora in its vertical orientation is illustrated in Figure 3-93. Note that once the remora has been upended and before it is mated to the platform, it will have a small pitch angle with the top of the remora leaning away from the platform. This is a desirable feature for the mating process, discussed below.

Table 3-38. Weight Summary for Remora Iteration 2.1 in Vertical Orientation

		Wt (kg)	
Group 1	Structure		
	Structure	2094830	
	Ballast	1844388	
Group 5	Auxiliary Systems		
	Systems	1282946	
	Water	2819700	
Group 6	Outfit & Furnishing	9790	
Total	Full Load (no water)	3387566	
	Full Load (w/ water)	8051654	
		Full Load	Full Load
Center of Gravity		(no water)	(w/ water)
	LCG (m)	48.5	54.4
	VCG (m)	7.28	7.84
	TCG (m)	0.00	0.00

Table 3-39. CG Location for Remora Iteration 2.1 in Vertical Orientation

		Full Load	Full Load
Center of Gravity		(no water)	(w/ water)
	LCG (m)	48.5	54.4
	VCG (m)	7.28	7.84
	TCG (m)	0.00	0.00

The weight of the remora in its horizontal, transit orientation is presented in Table 3-40. A detailed weight report for the remora in its transit condition is included in Appendix 3.3-15. In this configuration, all of the ballast tanks are empty, but the warm water system (on the bottom) is flooded and some of the cold water system is flooded.

The CG location for the remora in its horizontal, transit, orientation is summarized in

Table 3-41. The coordinate and reference system for CG in this orientation is the same as was used its vertical orientation. The remora in its transit configuration is also shown in Figure 3-93. The transit configuration is discussed in more detail below.

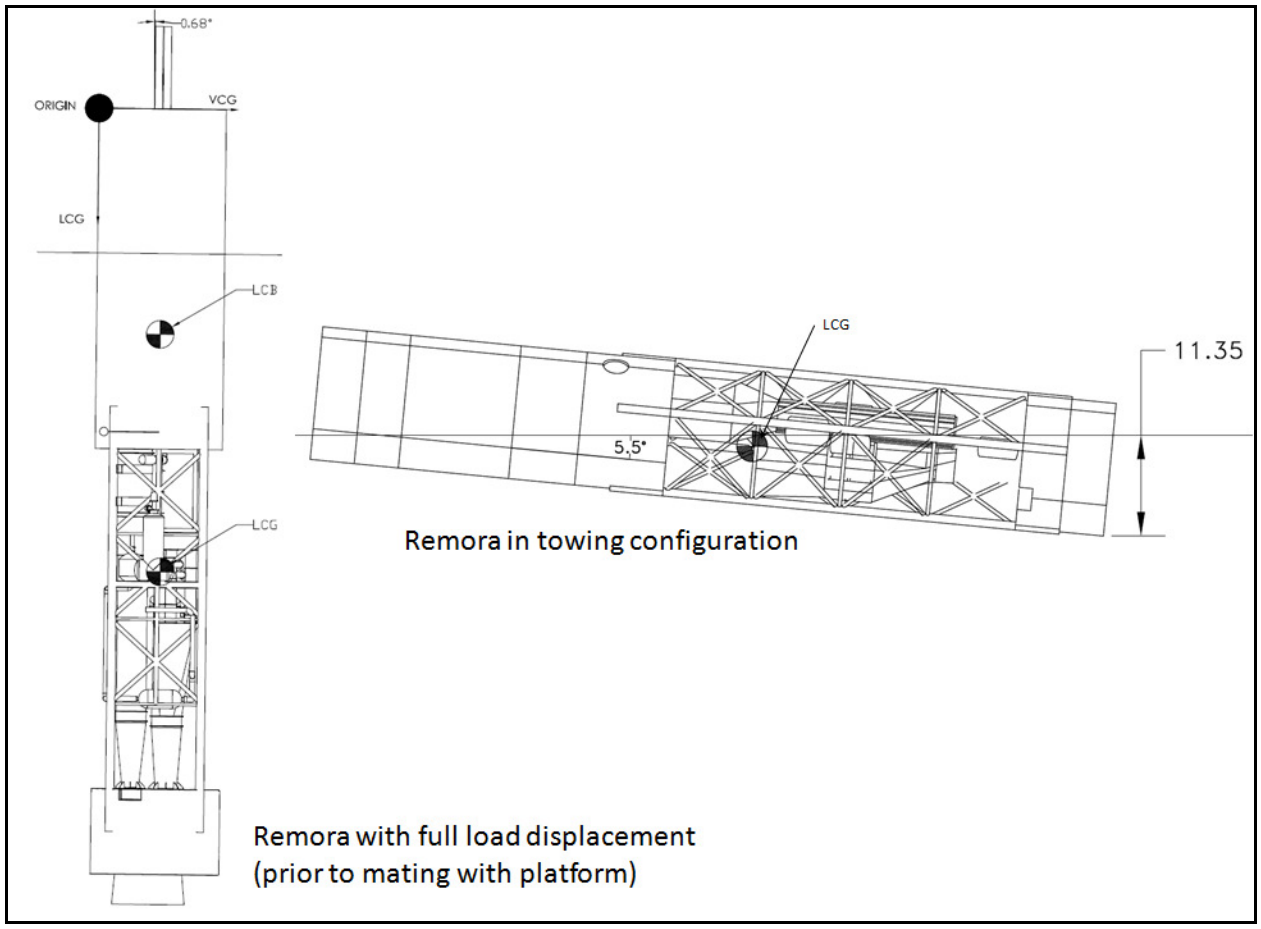


Figure 3-93. Remora in Vertical and Horizontal Orientations

Table 3-40. Weight Summary for Remora Iteration 2.1 in Transit Configuration

		Wt (kg)
Group 1	Structure	
	Structure	2094830
	Ballast	0
Group 5	Auxiliary Systems	
	Systems	1179445
	Water	2065937
Group 6	Outfit & Furnishing	9790
Total	Full Load (no water)	3284065
	Full Load (w/ water)	5350002

Table 3-41. CG Location for Remora Iteration 2.1 in Horizontal Configuration

		Full Load
Center of Gravity		(w/ water)
	LCG (m)	49.5
	VCG (m)	6.25
	TCG (m)	0.00

Hydrostatics and Stability

A summary of the enclosed volume of the remora, Iteration 2.1, is presented in Table 3-42.

As noted previously, the two possible orientations for the remora-horizontal for transit and vertical for deployed-have different ballast requirements. The remora ballast tanks are defined in Figure 3-94. As shown, the hard tank includes two ballast tanks, ballast tank #1 for the docking condition and ballast tank #2 for draft control when in the deployed orientation. It should be noted in this figure that the centerline longitudinal bulkheads provided in the ballast and soft tanks are required to constrain the ballast water to the submerged portion of the remora and to keep the remora from arbitrarily rolling while in the transit orientation and during towing.

Table 3-42. Enclosed Volume Summary of the Remora Iteration 2.1

Upper Hull (m^3)	7069
Mid-Section Truss (m^3)	218
Trunking & Tanks (m^3)	419
Lower Hull (m^3)	1767
Total (m^3)	9474
Full Load Wt Est (mt)	3388
Struct Wt Est (mt)	2261
Struct Vol Fraction	0.24
Struct Wt Fraction	0.67

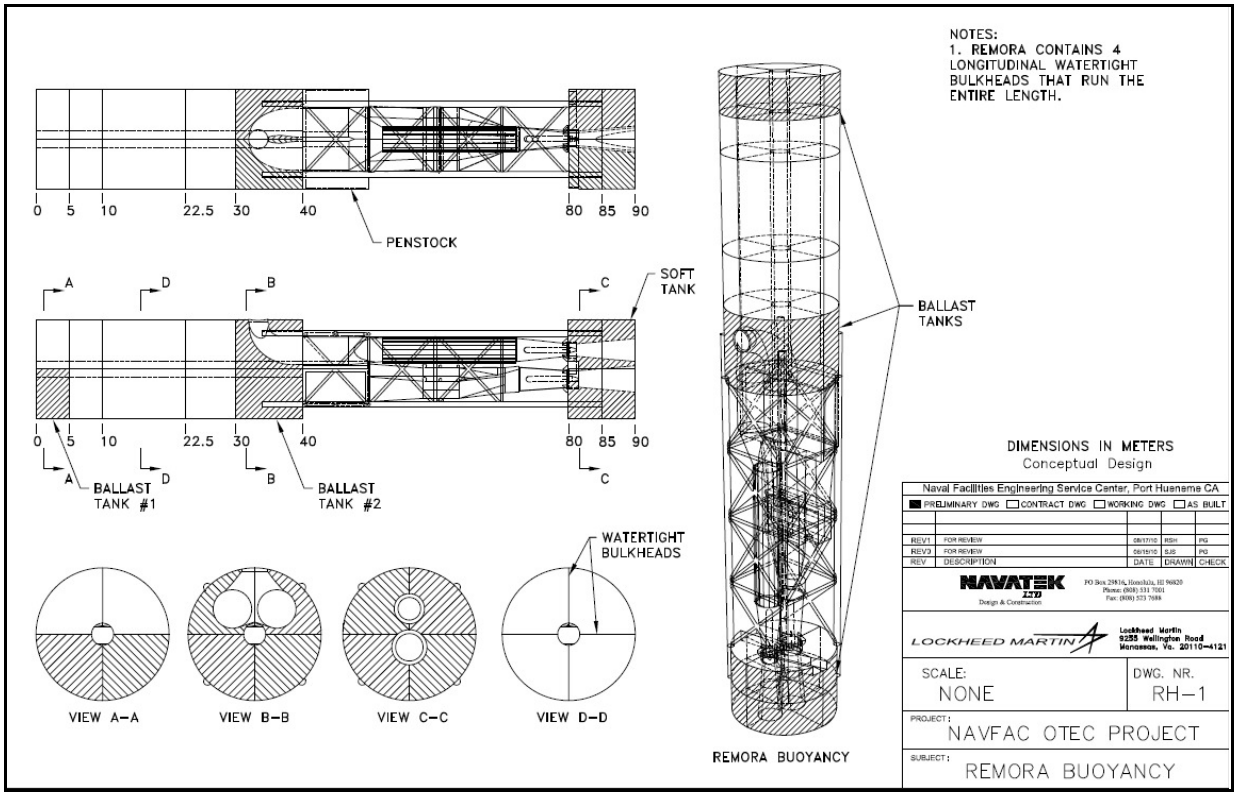


Figure 3-94. Buoyancy and Ballast Tank Definition for Remora Iteration 2.1

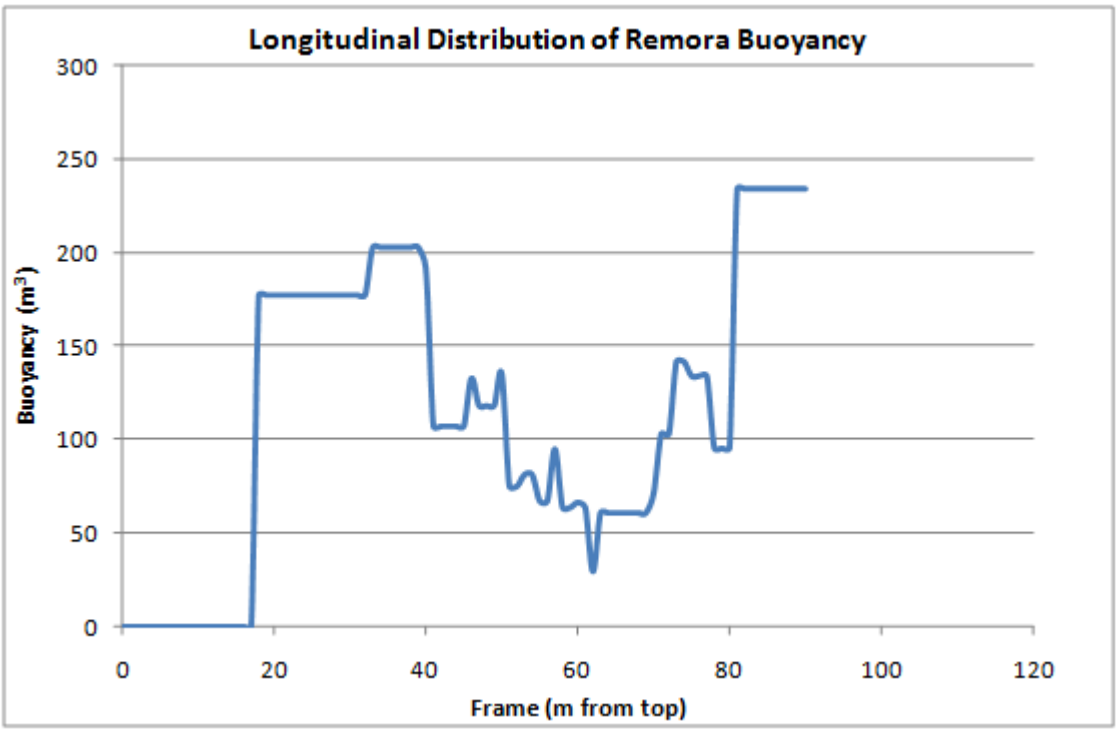


Figure 3-95. Longitudinal Distribution of Buoyancy for Iteration 2.1

The longitudinal distribution of buoyancy for the remora, Iteration 2.1, is presented in Figure 3-96. In this figure, the remora is assumed to be in its deployed orientation with no ballast tanks flooded.

The longitudinal distribution of weight for the remora in its full load condition, vertical orientation, is presented in Figure 3-96 and a comparison of the longitudinal buoyancy and weight distribution is presented in Figure 3-97. And, finally, the longitudinal buoyancy and weight distributions are compared with the longitudinal structural weight distribution in Figure 3-98. The detailed calculations of these longitudinal distributions can be found in Appendix 3.3-16.

As shown, the longitudinal distributions of buoyancy and weight roughly track each other resulting in reduced self-induced bending moments. These figures do illustrate the anticipated high loads likely at the joint between the hard tank and the truss structure.

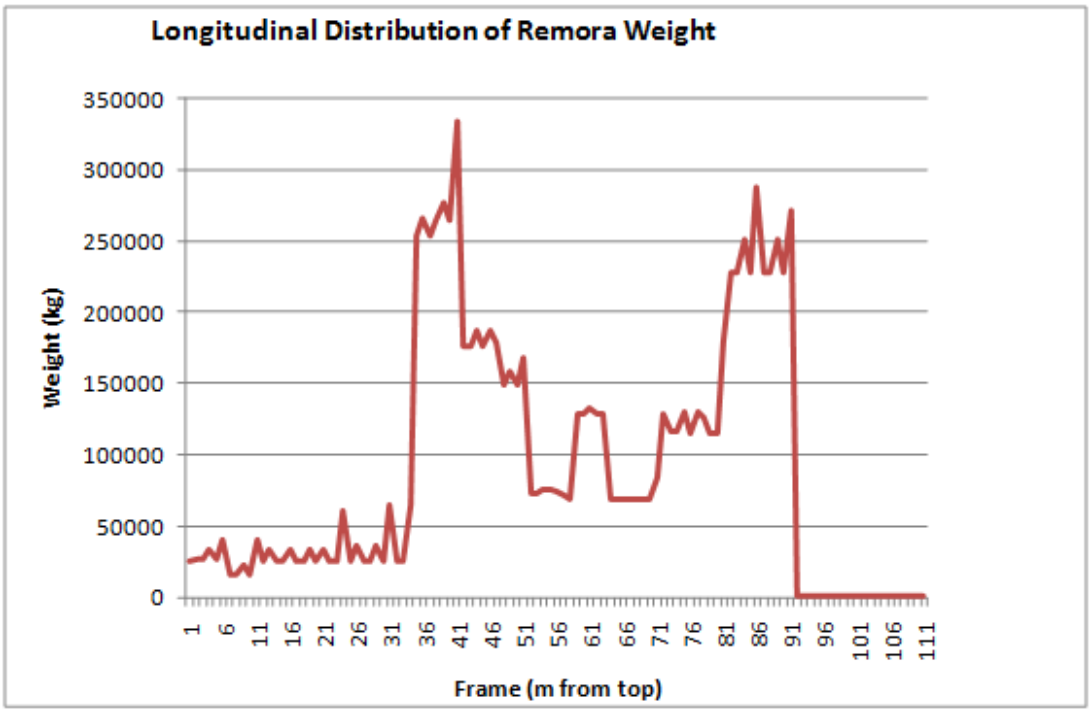


Figure 3-96. Longitudinal Distribution of Weight for Iteration 2.1

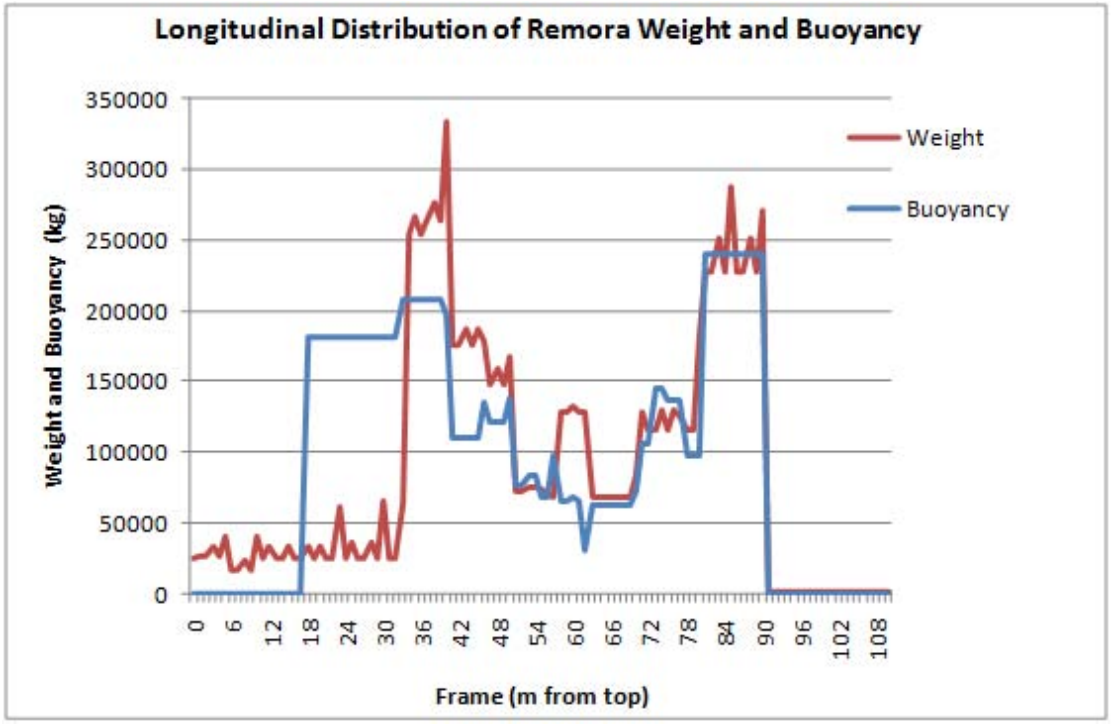


Figure 3-97. Comparison of Buoyancy and Weight Longitudinal Distributions for Iteraion 2.1

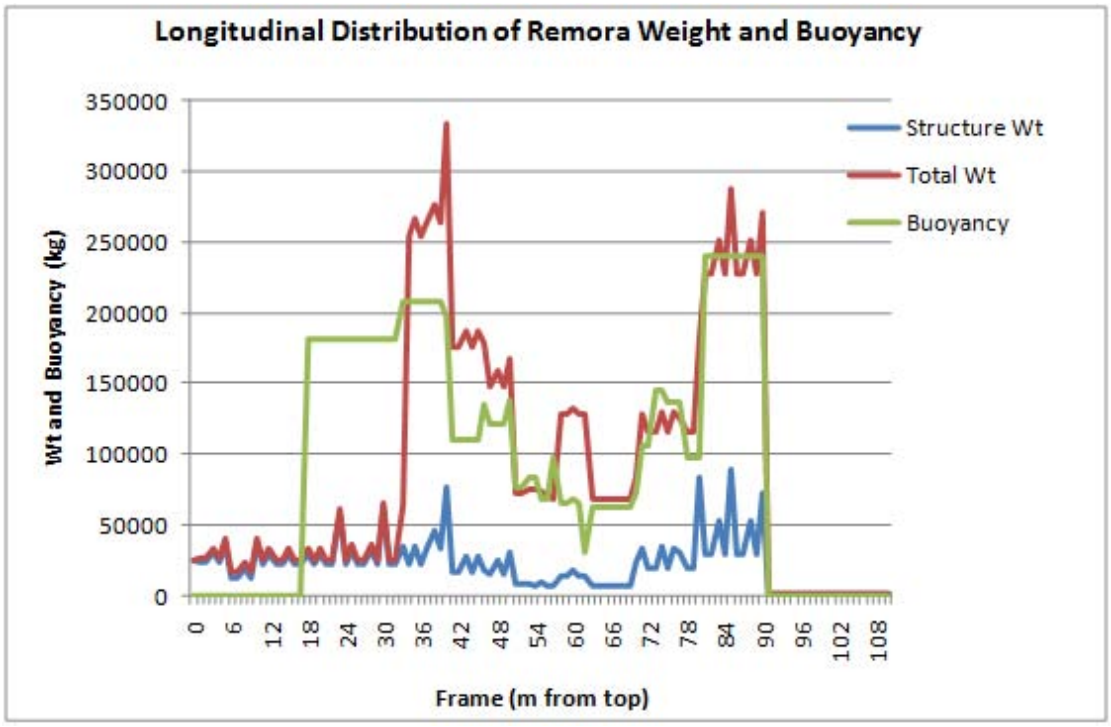


Figure 3-98. Comparison of Longitudinal Structural Weight Distribution with Buoyancy and Weight Distribution of Iteration 2.1

A summary of the mass moments of inertia and gyradii for the remora in its deployed iteration are presented in Table 3-43. In this table the point of reference is the centerline of the remora at the top. I_{xx} and I_{yy} represent the longitudinal axes of rotation and I_{zz} represents the vertical axis of rotation. As is expected the values for I_{xx} and I_{yy} are very similar and an order of magnitude larger than I_{zz}-not surprisingly it is much harder to rotate the remora longitudinally than to spin it. Detailed calculations of the remora's mass moments of inertia and gyradii are presented in Appendix 3.3-17.

Table 3-43. Summary of Mass Moment and Gyradii for Iteration 2.1 in Deployed Orientation

	I_{xx} (kg-mm^2)	I_{yy} (kg-mm^2)	I_{zz} (kg-mm^2)
Structure	13987597498324100	13987821480368000	182659675902378
Auxiliary Systems	11453936474294200	11467016689034000	79250193133027
Total	25441533972618400	25454838169402000	261909869035405
	k_{xx}	k_{yy}	k_{zz}
Gyradius (mm)	60243	60259	6112

Remora Towing and Docking

Construction, towing and docking the remora with facilities in Hawaii are not trivial problems. Figure 3-99 illustrates the dry docking of the remora in both Pacific Shipyard, Inc's (PSI) dry dock and Dry Dock #4 at Pearl Harbor Naval Shipyard. An early draft of a towing and docking CONOP is provided in Appendix 3.3-18. It should be noted that Figure 3-99 was prepared using weight data that has since been revised. This analysis is close should be reviewed as weight data continues to be refined.

Two dry docking facilities for construction and servicing the remora are available in Hawaii: PSI's dry dock and Dry Dock #4 at the Pearl Harbor Naval Shipyard. For reasons primarily of cost and availability, PSI's dry dock is the preferred facility for construction and dry docking of the remora. PSI's dry dock currently has a 6m draft limitation and the remora Iteration 2.1 is a very large structure for PSI facilities. The 2008 9m remora design fit into PSI's dry dock and facility fairly comfortably. Iteration 2.1, with its larger diameter and significantly greater structural weight, poses challenges for the PSI dry dock and facility:

- While in the dry dock, the remora must remain at a level trim;
- Maintaining a level trim of the remora and a draft of less than 6m is challenging and will have to be monitored during construction and servicing;
- Supplemental lift will be required to help support the end of the remora during dry docking for construction and servicing;
- Construction of the remora in modules and then assembly of the modules in the dry dock is an option that may improve the logistics, but has not been addressed at this time.

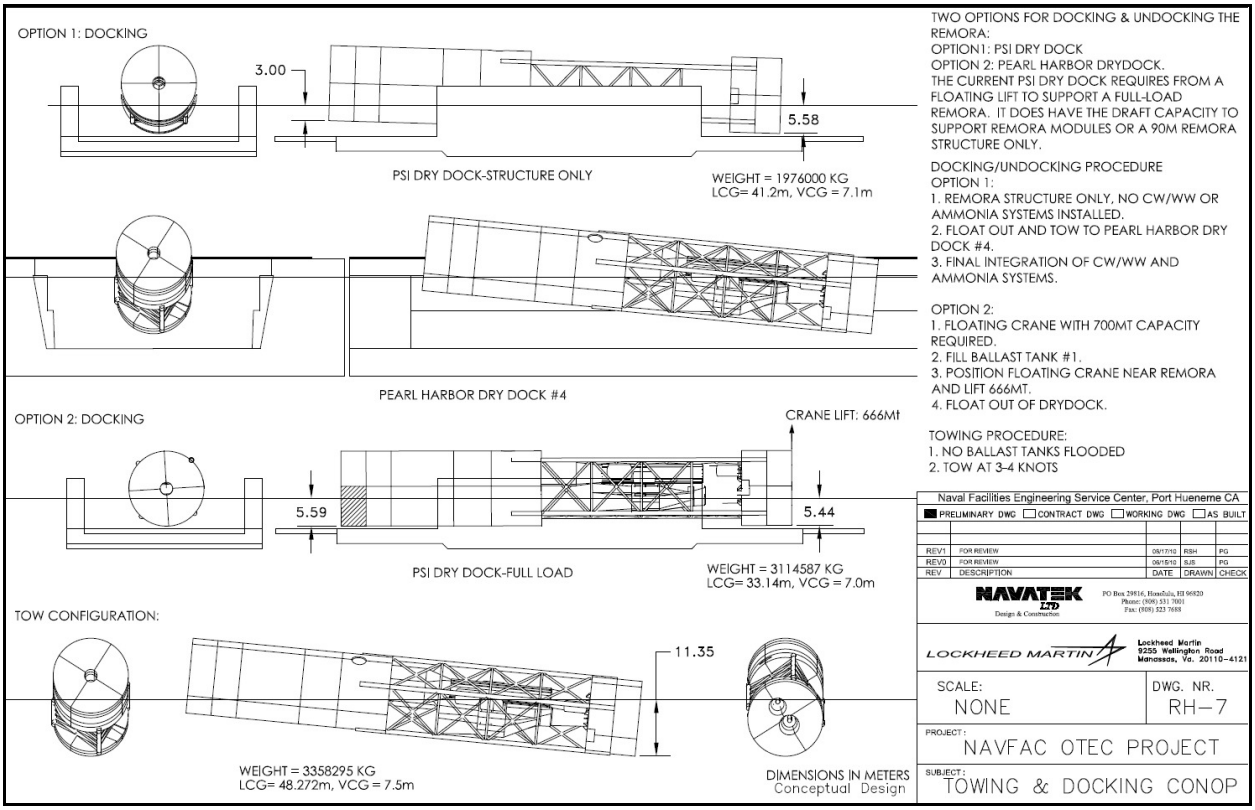


Figure 3-99. Remora Towing and Docking with Hawaiian Facilities

Dry Dock #4 at Pearl Harbor Naval Shipyard can accommodate the remora Iteration 2.1 with less difficulty than the PSI dry dock, however:

- Dry Dock #4 is at a naval shipyard whose primarily mission is support of the Navy's fleet
- Dry Dock #4 is likely to have less availability
- It may not be possible to tie up Dry Dock #4 for extended periods of time.

As a result, every effort must be made to design a remora that can be constructed using the PSI facilities. Future design work on the remora must include design modifications to make the remora more amenable to the PSI facilities, including:

- Reduced weight at the soft tank end of the remora;
- Consideration of alternatives for decreasing the draft of the remora while in the horizontal orientation;
- Installation of the seawater pumps after the remora has been upended at the site of the platform;
- Development of a modular approach to remora construction.

As shown in Figure 3-99 while being towed, it is proposed that all remora ballast tanks be emptied to reduce the towing weight. It is also proposed that the remora be towed with the warm water side down-the warm water side (and some of the cold water side) will flood during the tow. While under tow, the remora is not required to remain completely horizontal. An estimate of the remora tow force is presented in Figure 3-100. Appendix 3.3-19 provides remora towing weight and buoyancy calculations.

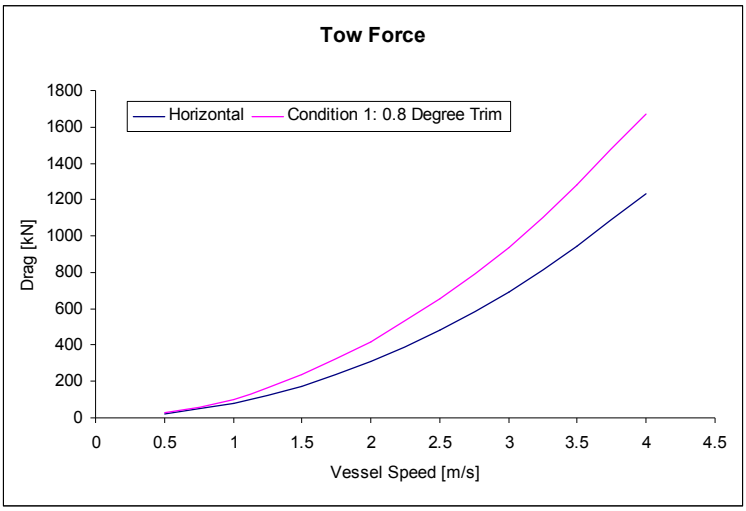


Figure 3-100. Estimated Tow Force for the Remora

Remora Upending

A key aspect of the remora installation procedure is the upending process that takes place once the remora has been towed out to the platform site. Figure 3-101 illustrates the upending process. A draft CONOPS for upending is also included in Appendix 3.3-20.

The upending process is initiated by flooding of one of the soft tank compartments and completed by filling the second soft tank compartment. The remora is kept in place with a tag line or two to a tug located well clear of the remora. It should be noted that the remora may rotate about its vertical axis as it upends.

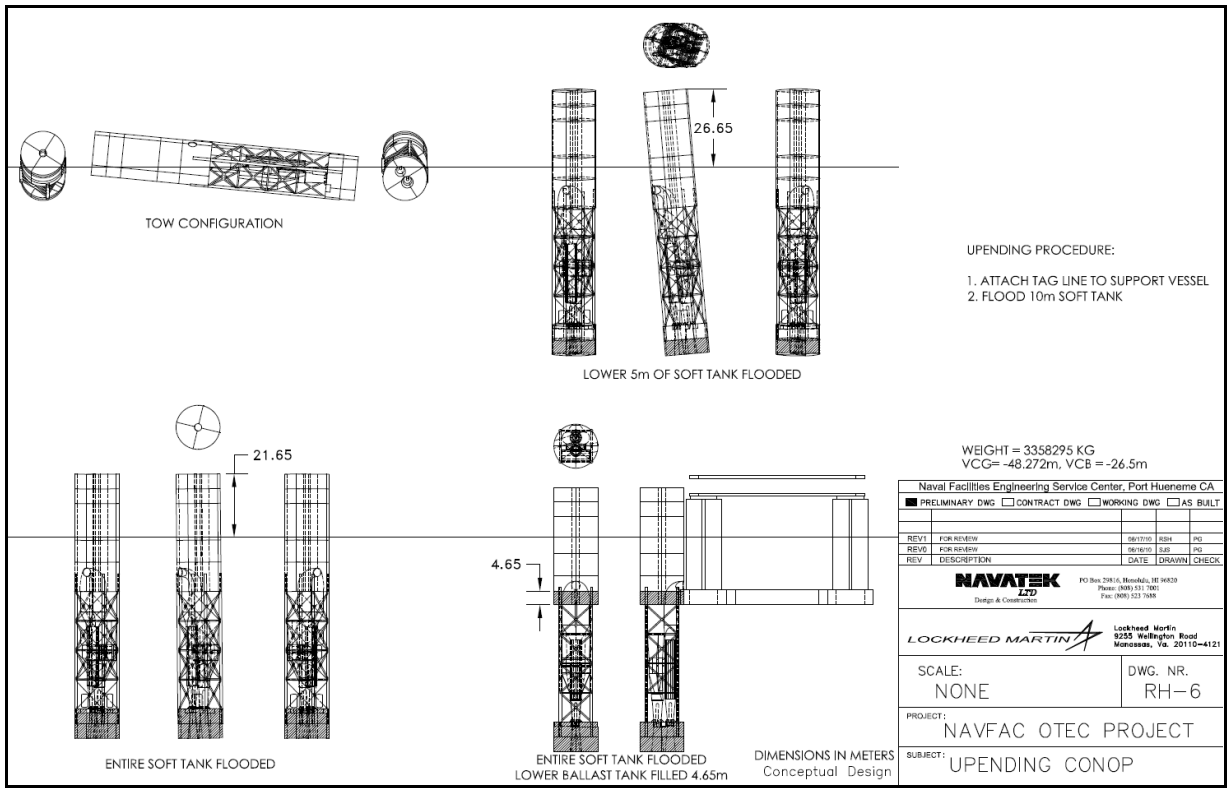


Figure 3-101. Remora Upending

3.3.2.1.1.2 Hull Structure

Environment and Component Loads

In addition to the seakeeping and load analyses performed specifically for the platform and in support of the Design Basis document, two additional seakeeping and load analyses were performed:

1. Kring, David, "Wave Interactions for the 100 MW OTEC Plant," Navatek, Ltd., 22 July 2010 (Appendix 3.3-21)
2. Hart, Christopher, "OTEC LAMP Relative Motion Study," Navatek, Ltd., 16 June 2010 (Appendix 3.3-22)

The purpose of the Kring study was to supplement the original WAMIT seakeeping analysis for the platform with analysis using AEGIR that included the effects of a 5-knot current on the wave loading on the platform. Preliminary findings from the study included:

- Good agreement between WAMIT and AEGIR for the zero speed cases.
- Results for heave added mass showed little difference between the approximate method (WAMIT) and the exact description of the current in AEGIR. However, there were some significant differences in the wave damping forces.

- Consideration of the effective Froude number and reduced frequencies indicate that significant interactions should be expected in a current of 5 knots. At 5 knots, the critical reduced frequency is encountered, where the group velocity of the radiated waves travels at the same speed as the current. At 2 knots, the critical frequency would not be encountered, so WAMIT would be more suitable.

The purpose of the Hart study was to derive an estimate of loads between the remora and the platform while mating the remora to the platform at a low sea state. Key findings from this study include:

- The analysis was originally done with six degrees of freedom; however the platform and the remora drifted apart. As a result the analysis was redone with three degrees of freedom-heave, pitch and roll.
- In low sea states the motions of both the remora and the platform are most heavily influenced by the long period swell.
- The long period swell typical of Hawaiian waters, and more specifically, the site of the pilot plant is very close to the natural heave period of the remora in its vertical orientation. As a result, the remora moves with respect to the platform significantly.
- The loads between the remora and the platform, while still unmated, even in low sea states are very high. It is recommended that the sea state specified in the Design Basis for the platform/remora mating operation be revisited and lowered.
- The predicted loads between the remora and the platform in a 1.5m sea state were used to design the lower mating mechanism on the platform.

An example of the predicted relative motions between the remora and the platform is presented in Figure 3-102. This figure shows relative motions in a sea state 4, though it was subsequently determined that a sea state 4 is too large a sea state for the mating/demating process.

Structural Design

The general process for the design of the remora structure was as follows:

Remora Primary Structure

1. 1st Cut-design structure to the American Bureau of Shipping (ABS) Floating Production Installation (FPI) Rules and Mobile Drilling Unit (MODU) Rules. In some cases, the ABS Rules also referred out to American Petroleum Institute (API) Recommended Practices for Planning, Designing and Constructing Fixed Offshore Platforms-Working Stress Design (RP 2A-WSD);
2. Structural review and lessons learned from Horton Wison;
3. 2nd Cut-incorporate lessons learned to revise structure. Ensure revised structure still met the ABS FPI and MODU Rules;
4. Apply estimated seaway loads to critical portions of the remora structure.

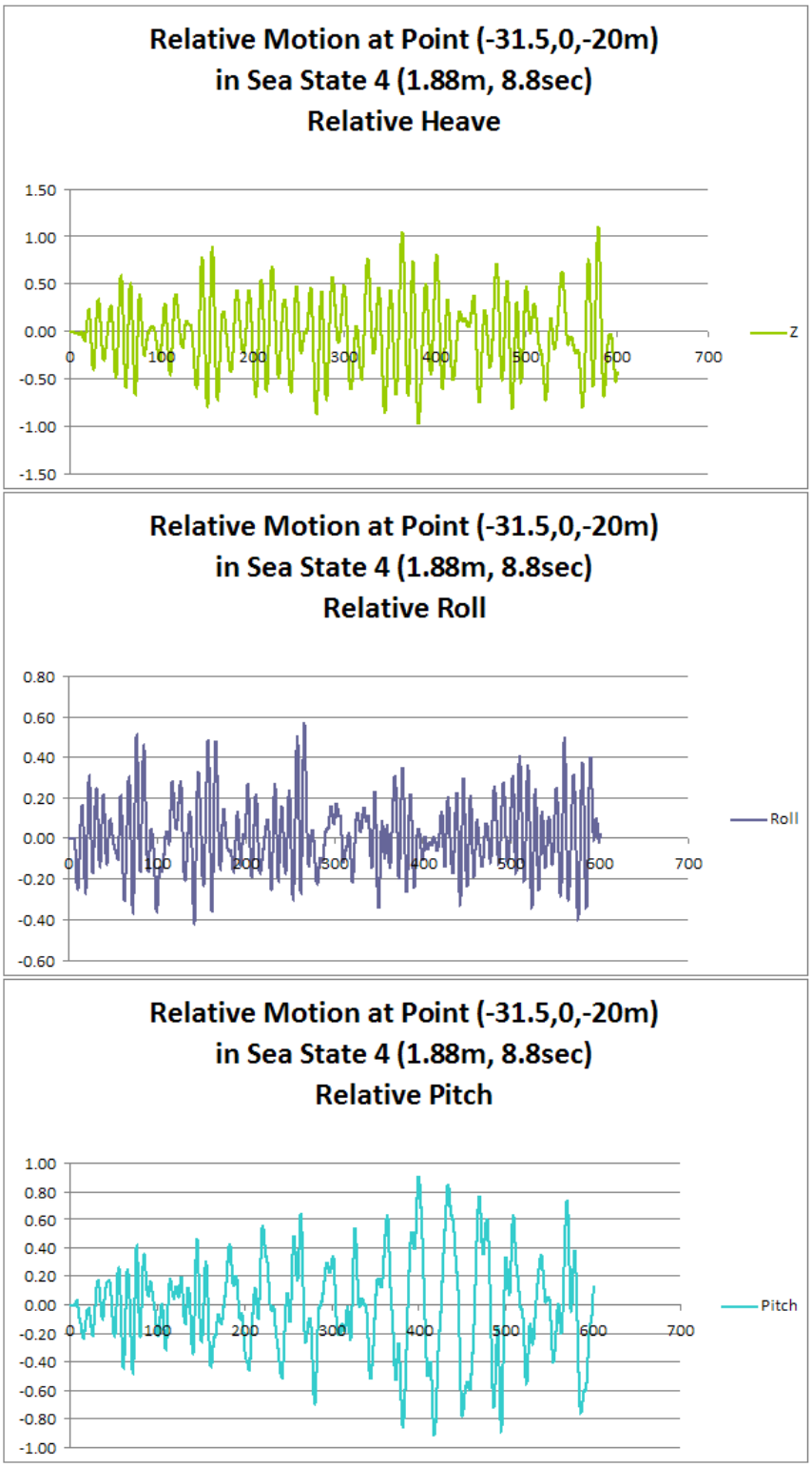


Figure 3-102. Predicted Relative Motions Between Remora and Platform from (Large Amplitude Motions Program (LAMP) in a Sea State 4

Remora Local Loads

1. Estimate loads for the heaviest seawater system components such as the heat exchangers and seawater pumps
2. Configure a draft seawater equipment foundation structure
3. Analyze truss structure to confirm the ability of the truss to withstand seaway loads and accommodate the seawater equipment loads.

A general arrangement of the remora Iteration 2.1 primary structure is presented in Figure 3-103. Definition of the scantlings is presented in Figure 3-104.

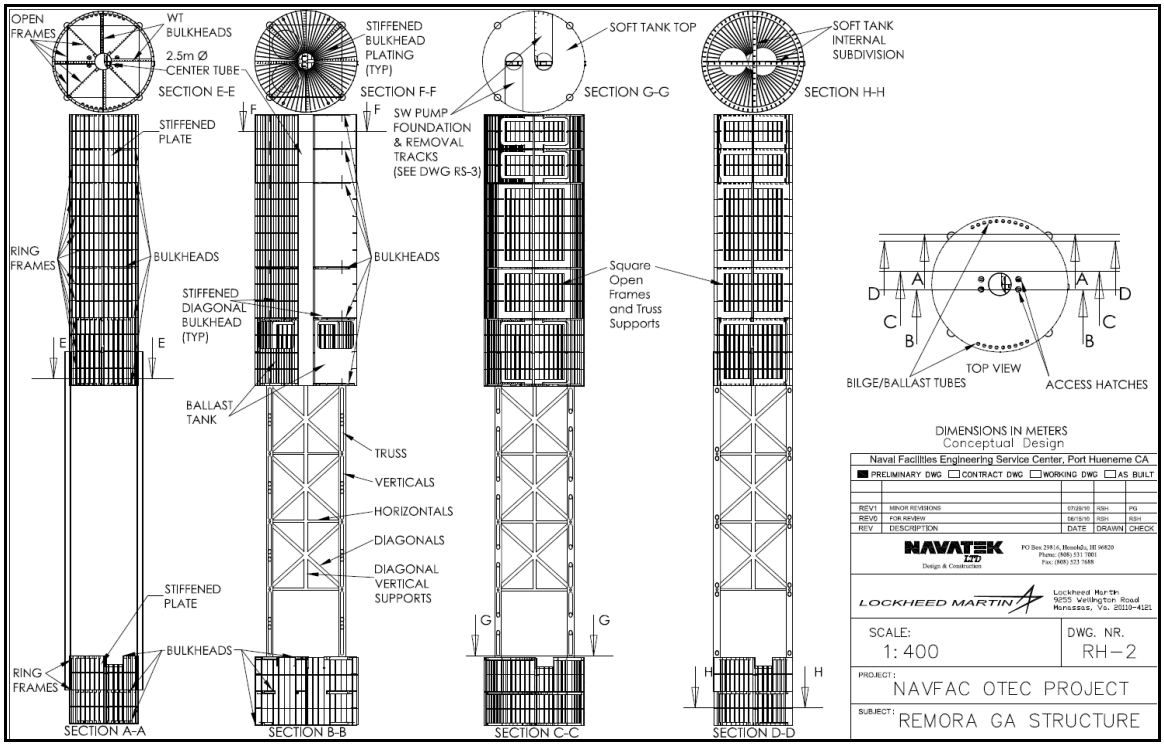


Figure 3-103. General Arrangement of Remora Iteration 2.1 Structure

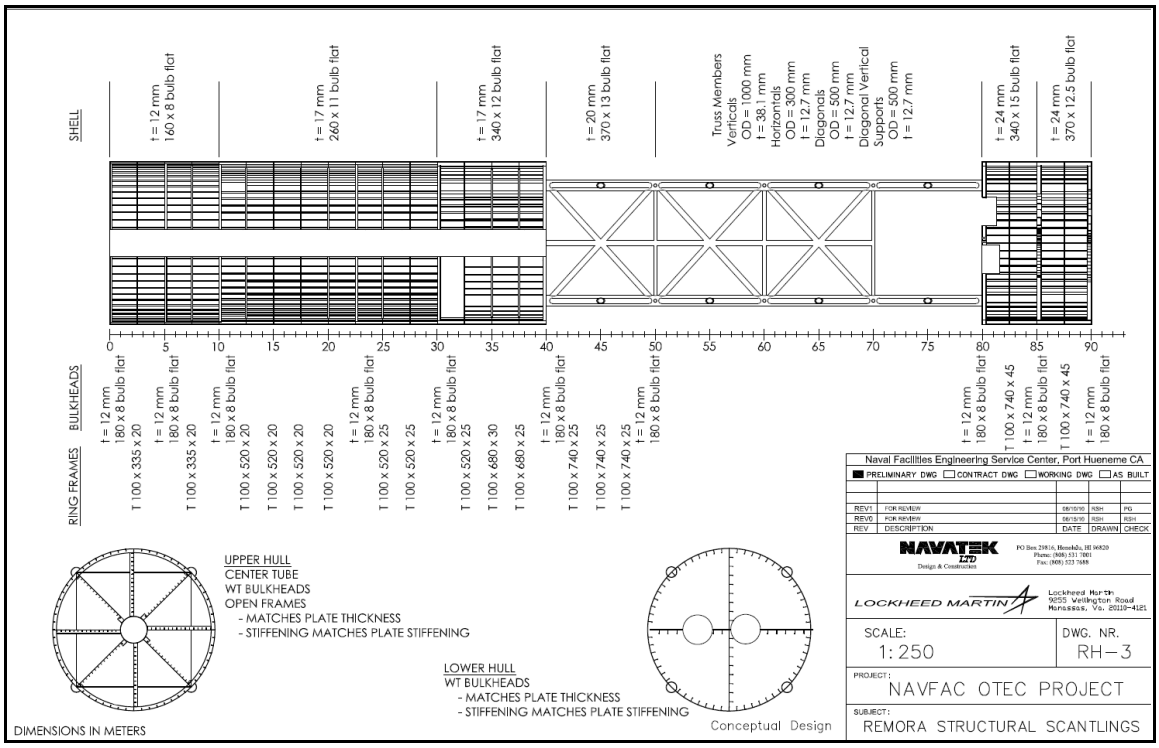


Figure 3-104. Definition of Scantlings for Remora Iteration 2.1

A comparison of the structural weight of the various remora iterations is presented in Table 3-44. In this table, Iteration 0 is the square-sectioned, fully enclosed spar, Iteration 1 is the square-sectioned truss configuration and Iteration 2 is the first circular truss configuration. It is difficult to draw too many conclusions from this table since the structural weight estimate for Iteration 2.1 includes a great deal more detail than the earlier weight estimates. However, it is clear that substantial structural weight savings were gained from the following:

- Changing from a fully enclosed structure requiring a great deal of plate to an open truss structure saved considerable structural weight;
- Incorporating the lessons learned from Horton Wison resulted in a significantly more weight efficient structure.

The structure for both Iteration 1 and Iteration 2.1 was designed to the ABS FPI Rules, without the benefit of the experience in offshore structures in general and specifically spar trusses that has been gained by Horton Wison. The details of these initial structures have been included in Appendix 3.3-41. Dick Davies of Horton Wison reviewed the initial structural design of Iteration 2 and made numerous recommendations. Incorporation of those revision resulted in Iteration 2.1. The Horton Wison report is included in Appendix 3.3-23. The detailed calculations for sizing the structure of Iteration 2.1 have been included in Appendix 3.3-24.

Table 3-44. Comparison of Remora Iteration Structural Weights

		Iteration 0	Iteration 1	Iteration 2	Iteration 2.1
Configuration		15m Square Plate	15m Square Truss	15m Dia Circular	15m Dia Circular
Structure					
	Plate & Bkhds (mt)	3229	1556	1002	1058
	Scantlings (mt)	163	649	372	501
	Truss (mt)		369	229	266
	Miscellaneous (mt)	295	270	362	269
Total Structure (mt)		3687	2844	1965	2094

This table shows seven percent weight growth between Iteration 2 and Iteration 2.1. The majority of these increases were due to more detailed calculation of structural foundations and components, so that Iteration 2.1 is a significantly more mature design than the earlier versions. Within the remora hull structure itself, numerous weight reductions were made through lessons-learned provided by the experienced spar design firm Horton Wison. These include:

Significantly reducing plate, bulkhead and deck frame spacing which resulted an increase in the number of stiffeners but significantly reduced the size of the stiffeners and the thickness of the hull, deck and bulkhead plating;

- Adding a center tube in the hard tank to reduce the span and, therefore, the size of deck stiffeners and frames;
- In the truss, reducing tube diameter and increasing tube wall thickness;
- Incorporating a proven method for attaching the truss to the hard and soft tanks;
- Incorporating a proven method for transferring truss loads into the hard tank plate, deck and frames;
- Reducing the number of watertight bulkheads and replacing some watertight bulkheads with ring frames;
- Minimizing personnel access and personnel support features;
- Utilizing a proven, ABS-approved method for bilge and ballast.

After definition of the primary structure for remora Iteration 2.1 a finite element analysis (FEA) was conducted for the truss using load conditions provided in the Design Basis and additional seaway loads derived from WAMIT by John Halkyard and Associates. The FEA was performed using ALGOR and is illustrated in the following figures and in Appendix 3.3-25.

- Figure 3-105. Remora FEA Study-Truss Model Set-Up
- Figure 3-106. Remora FEA Study--Distributed Loads
- Figure 3-107. Remora FEA Study-Worst Case Stresses
- Figure 3-108. Remora FEA Study-Axial Stresses
- Figure 3-109. Remora FEA Study-Displacements

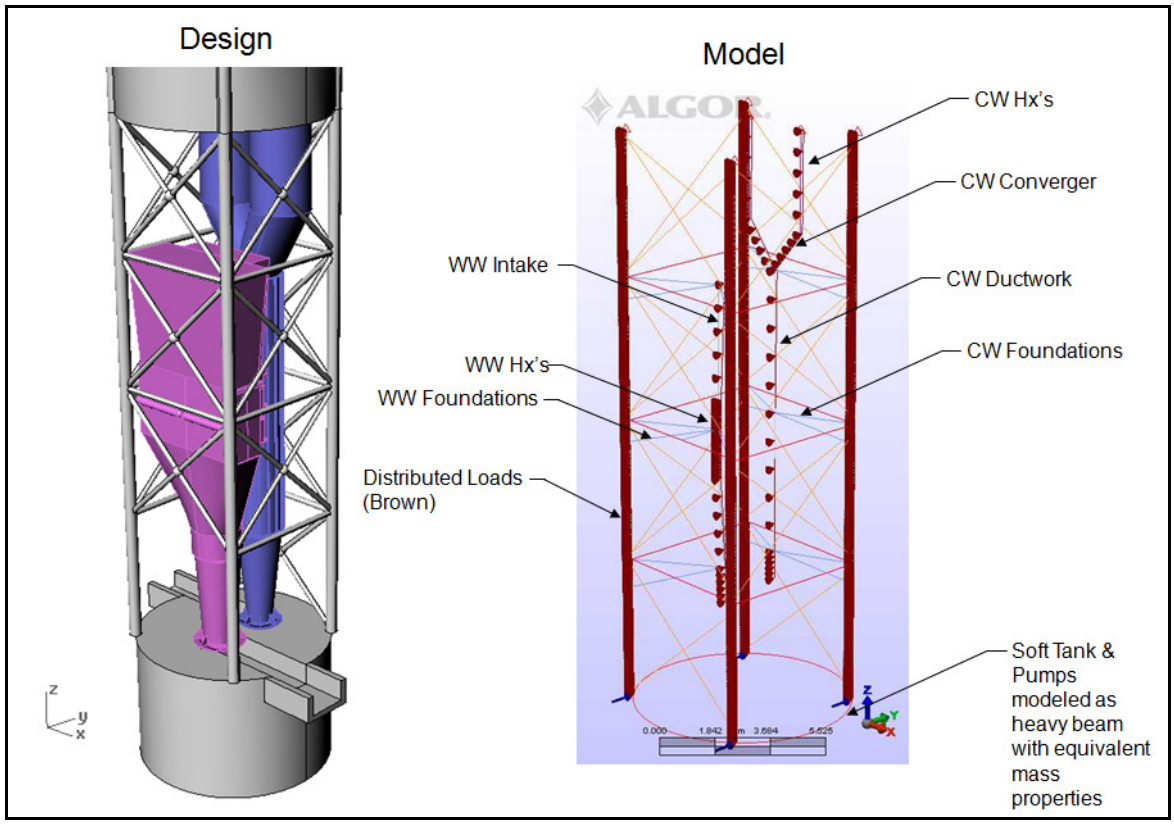
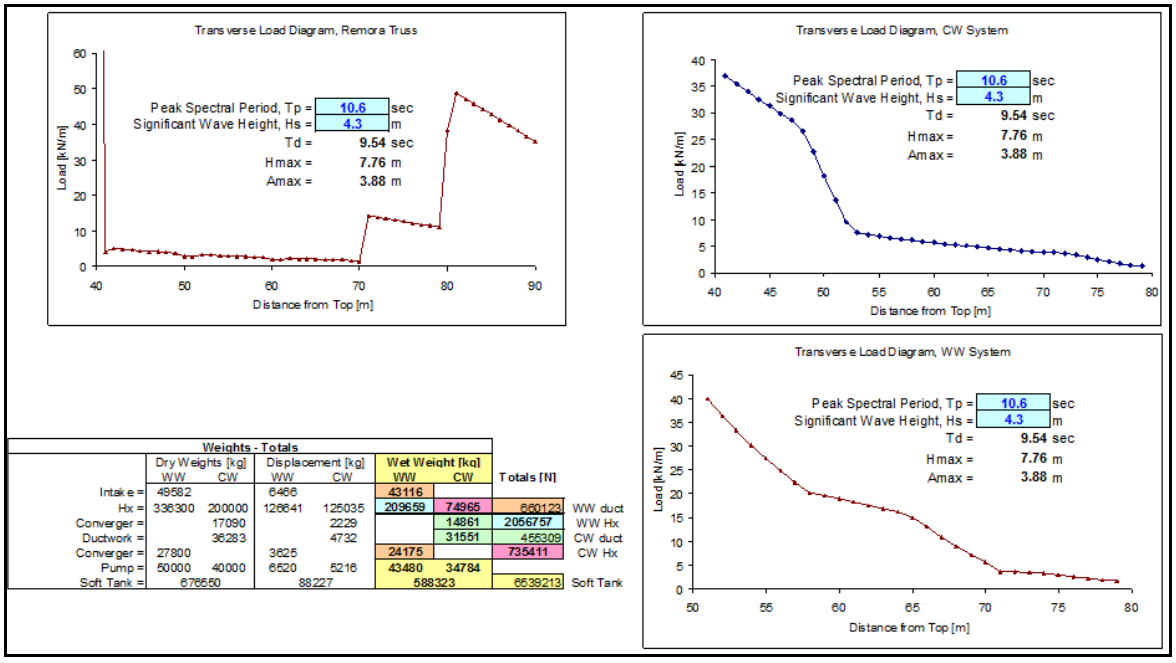


Figure 3-105. Remora FEA Study-Truss Model Set-Up



Weights - Totals

	Dry Weights [kg] WW	Dry Weights [kg] CW	Displacement [kg] WW	Displacement [kg] CW	Wet Weight [kg] WW	Wet Weight [kg] CW	Totals [N]	
Intake =	49582		6466		43116			
Hx =	336300	200000	126641	125035	209659	74965	660123	WW duct
Converger =		17090		2229		14861	2056757	WW Hx
Ductwork =		36283		4732		31551	455309	CW duct
Converger =	27800		3625		24175		735411	CW Hx
Pump =	50000	40000	6520	5216	43480	34784		
Soft Tank =	676550		88227		588323		6539213	Soft Tank

Figure 3-106. Remora FEA Study--Distributed Loads

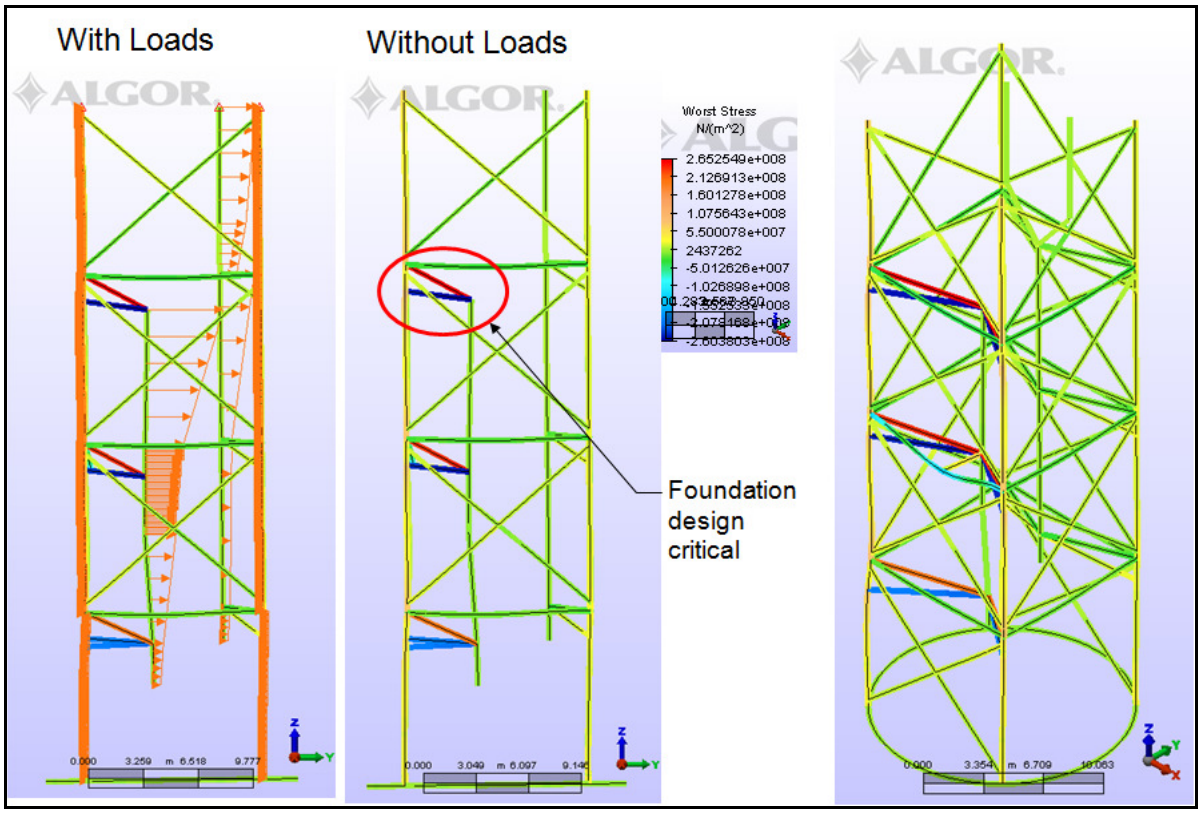


Figure 3-107. Remora FEA Study-Worst Case Stresses

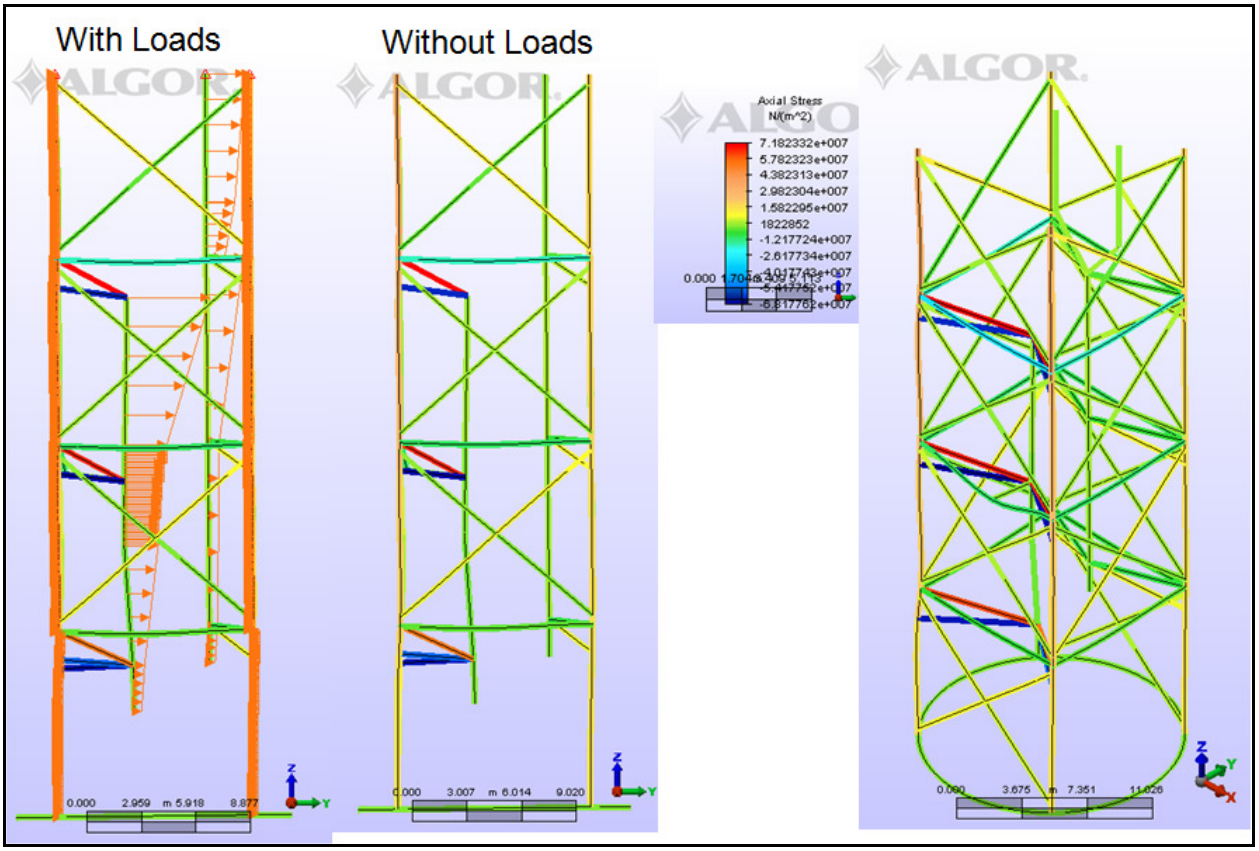


Figure 3-108. Remora FEA Study-Axial Stresses

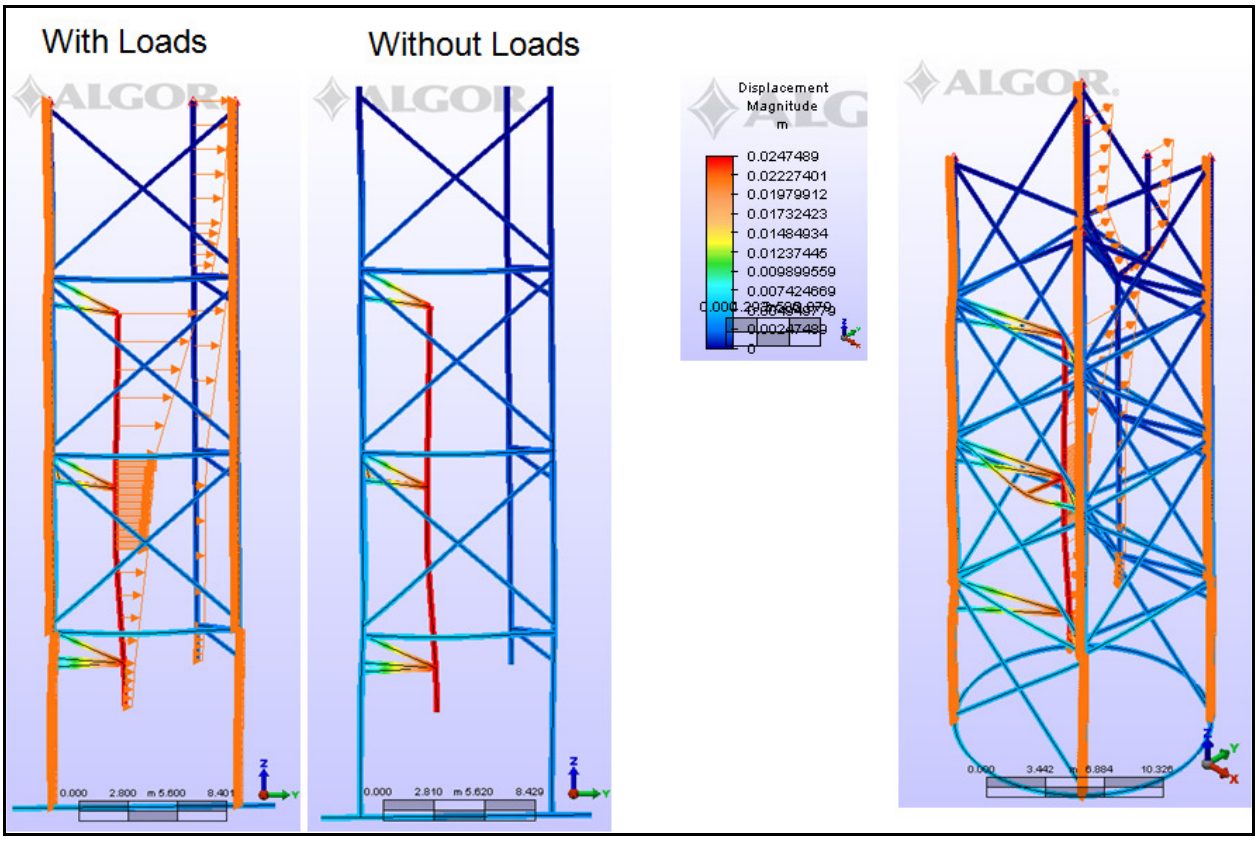


Figure 3-109. Remora FEA Study-Displacements

The results of the FEA study indicate that the truss structure as currently designed is sufficient to meet the seaway and seawater system loads. Additional FEA work is recommended as the seaway and structural loads and the structural design are refined.

The first draft of the foundations for the cold water condensers and the warm water evaporators are presented in Figure 3-110. These foundations, in particular the condenser foundation, require additional development.

The evaporator foundation is an assembly of identical I beams spanning the truss horizontals. The evaporators are flange-mounted to the I beams.

At the moment, the condensers are mounted to the vertical truss members by “belly” bands. As noted, additional work on the condenser foundations is required. It may be possible to mount the condenser foundations to the bottom of the hard tank.

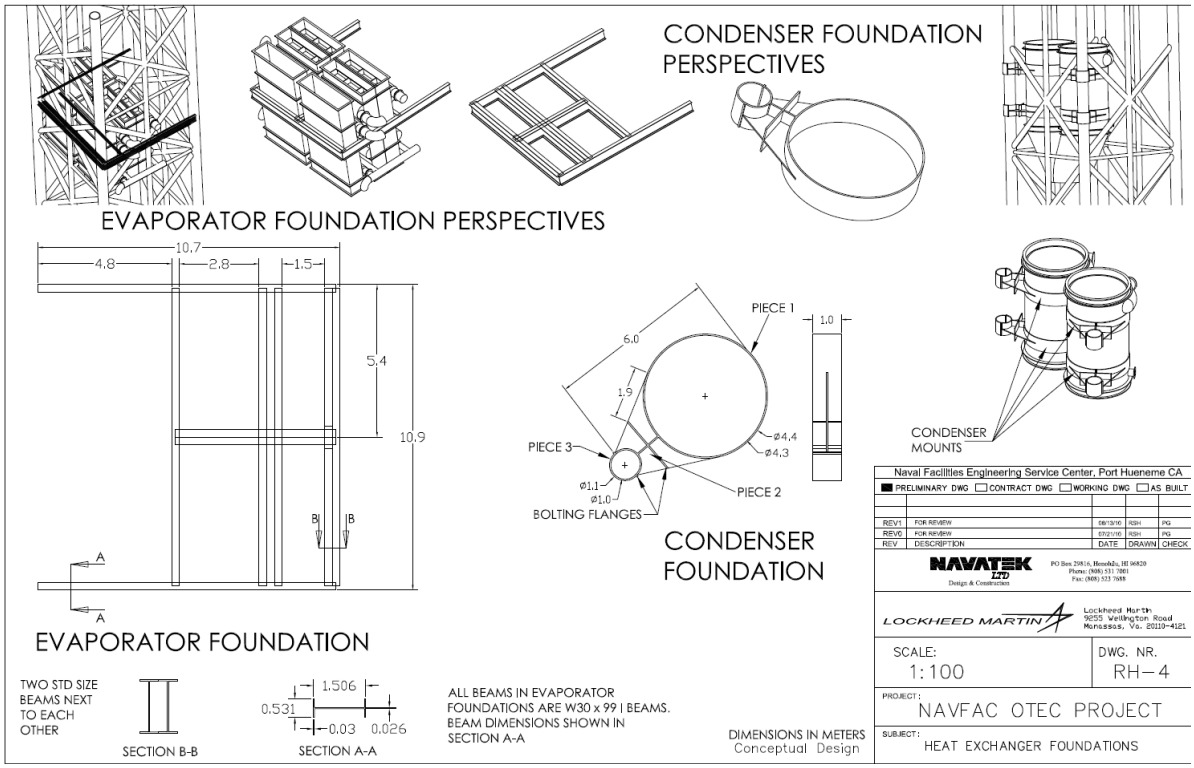


Figure 3-110. Condenser and Evaporator Foundations

3.3.2.1.1.3 Hull Auxiliary Systems

Auxiliary system requirements were also evaluated based on the ABS FPI and MODU Rules. On occasion, the MODU Rules referred out to the ABS Rules for Building and Classing Steel Vessels (SVR). As will be demonstrated in the following paragraphs, all major auxiliary systems were evaluated, but it was found that most were not required for the remora.

Ventilation System

ABS's FPI Rules require that all voids and tanks (except small ones) be fitted with vents. However, the FPI Rules also note that vent openings for hull voids may be sealed off at the spar deck level by means of a blank if:

- Voids are below WL
- Voids above WL to be fitted with rupture disk to account for thermal loads
- Voids not classified as hazardous areas
- Voids not fitted with permanently installed bilge or drainage system
- Voids are fitted with high bilge water level alarm

- Blank installed in readily accessible position and can be removed for routine de-watering and inspections
- Voids do not contain pressurized piping

The MODU Rules specify vent pipe heights, diameters and wall thicknesses.

Based on these requirements and the experiences of Horton Wison with other offshore spar structures it was decided that all watertight compartments in the hard tank would be equipped with vent tubes (that double as bilge tubes) and would be sealed with watertight seals at the top of the spar. Therefore the hard tank compartments would not be ventilated most of the time, but sealed with airtight seals. The oxygen in each compartment would be used up by corrosion and not replaced until visited by personnel for inspection. Compartments would have to be ventilated and gas-freed prior to inspection by personnel.

See the bilge/ballast system discussion below for a more thorough description of the ventilation piping.

Fire-Fighting System

The ABS FPI Rules fire-fighting requirements refer out to the MODU Rules. The MODU Rules require a fixed fire-fighting system for spaces housing particular types of machinery. Since none of the spaces in the hard tank house any machinery it was determined that no fixed fire-fighting system is required on the remora.

Portable fire-fighting equipment is proposed for installation on the platform in an area adjacent to the remora mounting.

Drainage and Ballasting

Ballast System

ABS FPI Rules require that the remora be equipped with a ballast capacity sufficient to ballast and deballast the remora with a list of up to 5° in any direction. They further require that at least two ballast pumps be provided, at least one of which is to be permanently connected to the ballast system. These Rules are very similar to the requirements of the MODU Rules.

As noted previously, the hard tank is equipped with several ballast tanks: upper tanks used when the remora in its horizontal orientation for transit and the lower tanks used for remora draft control when the remora is in its vertical, deployed, orientation. Ballast water to these tanks will be supplied through the bilge piping when required.

A portable bilge pump is to be located on the platform. One submersible ballast pump is to be installed in each of the four watertight subcompartments of the lower ballast tank.

The soft tank is also flooded when the remora is in its vertical orientation. This flooding is accomplished through holes in the structure. When preparing the remora for transit, the soft tanks are to be emptied by compressed air. The details of the compressed air system have not yet been resolved; however the compressed air is likely to be supplied by a separate support vessel, so compressed air is not required to be located on the remora.

See the bilge system in the following section for additional details on the bilge/ballast/ventilation piping.

Bilge System

The ABS FPI Rules require bilge pumps for all spaces, but allow the omission of a fixed bilge pumping system for void spaces in the spar hull. These Rules also specifically allow the use of portable pumps lowered into spaces through manholes and that at least two portable pumps with hoses and accessories be available at all times. MODU Rules further specify the dimensions for bilge piping and the required flow rates for the bilge system.

Based on these requirements and the experiences of Horton Wison with other offshore spar structures it was decided to provide the remora with two separate bilge pumps (including hoses and accessories) located on the platform adjacent to the remora boarding area. As shown in Figure 3-111, an arrangement of bilge piping has been designed to provide bilge pump access to all watertight compartments in the hard tank. The bilge piping details are similar to those proposed by Horton Wison for the platform structure bilge system, Figure 3-112.

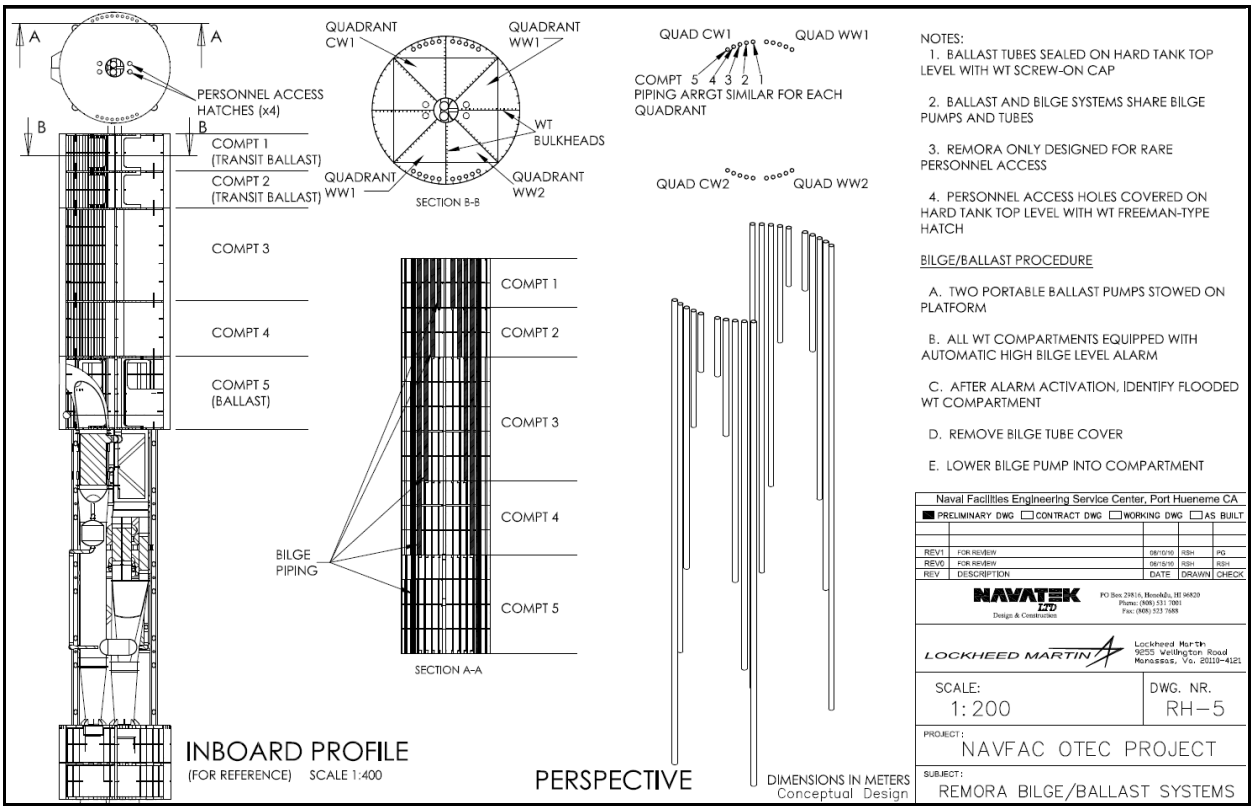


Figure 3-111. Bilge/Ballast/Ventilation Piping Arrangement for Remora Iteration 2.1

Bilge pump sizing calculations are provided in Appendix 3.3-26. A tentative bilge pump and its performance curve are presented in Figure 3-113. A bilge pump cut sheet and additional performance curves are also included in Appendix 3.3-26.

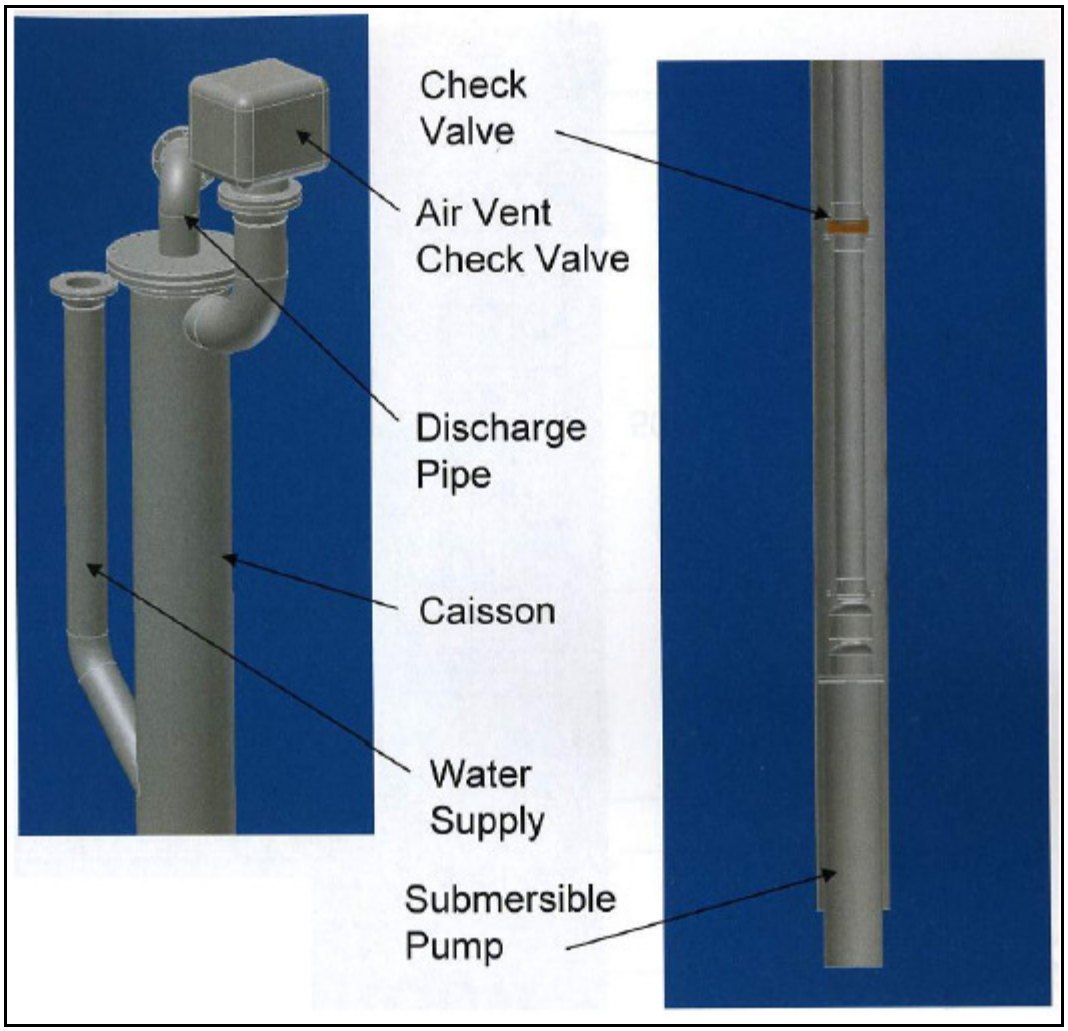


Figure 3-112. Bilge Piping Details for Remora Iteration 2.1

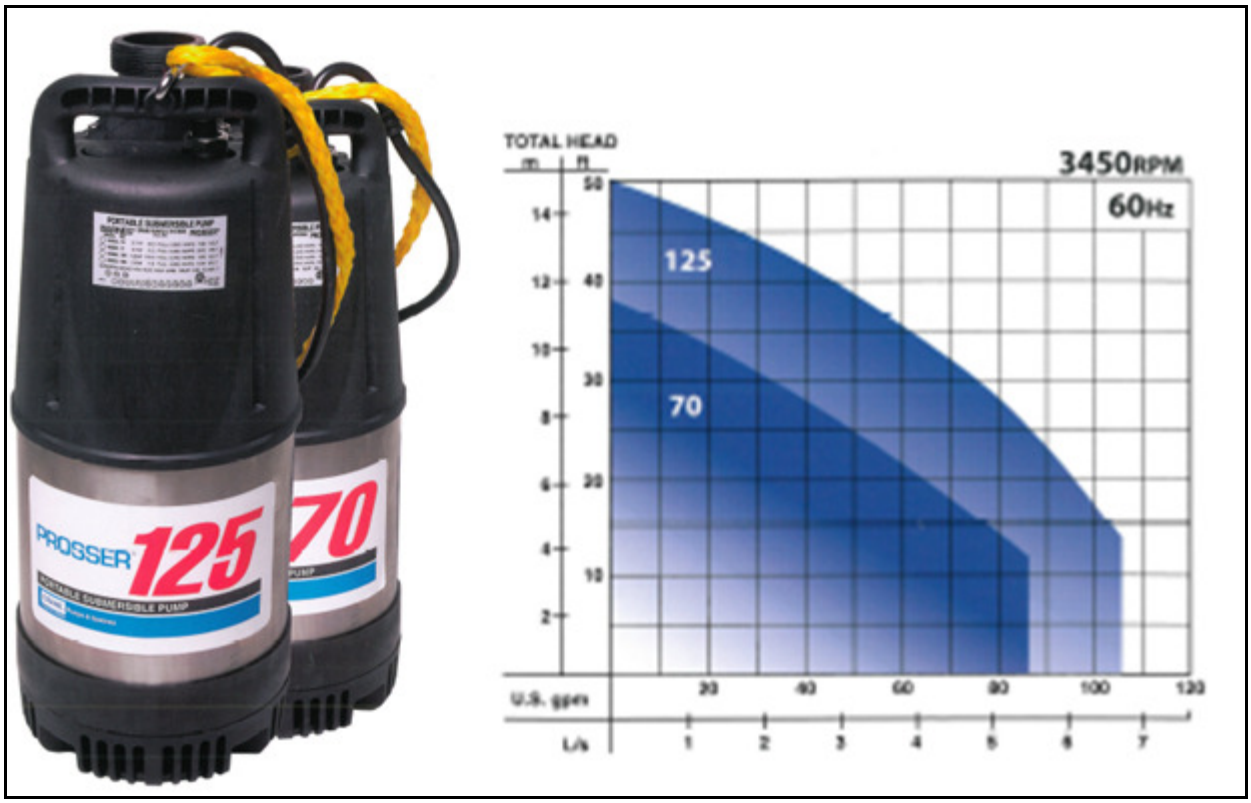


Figure 3-113. Proposed Bilge Pump and Performance for Remora Iteration 2.1

3.3.2.1.1.4 Hull Outfit and Furnishing

Mating and Demating

Mating and demating the remora and the platform are important operations for the OTEC system and for periodic maintenance on the remora. A draft CONOPS for the mating/demating process is included in Appendix 3.3-27. An outline of the procedure is presented in Figure 3-114 and in a more graphic form in Figure 3-115.

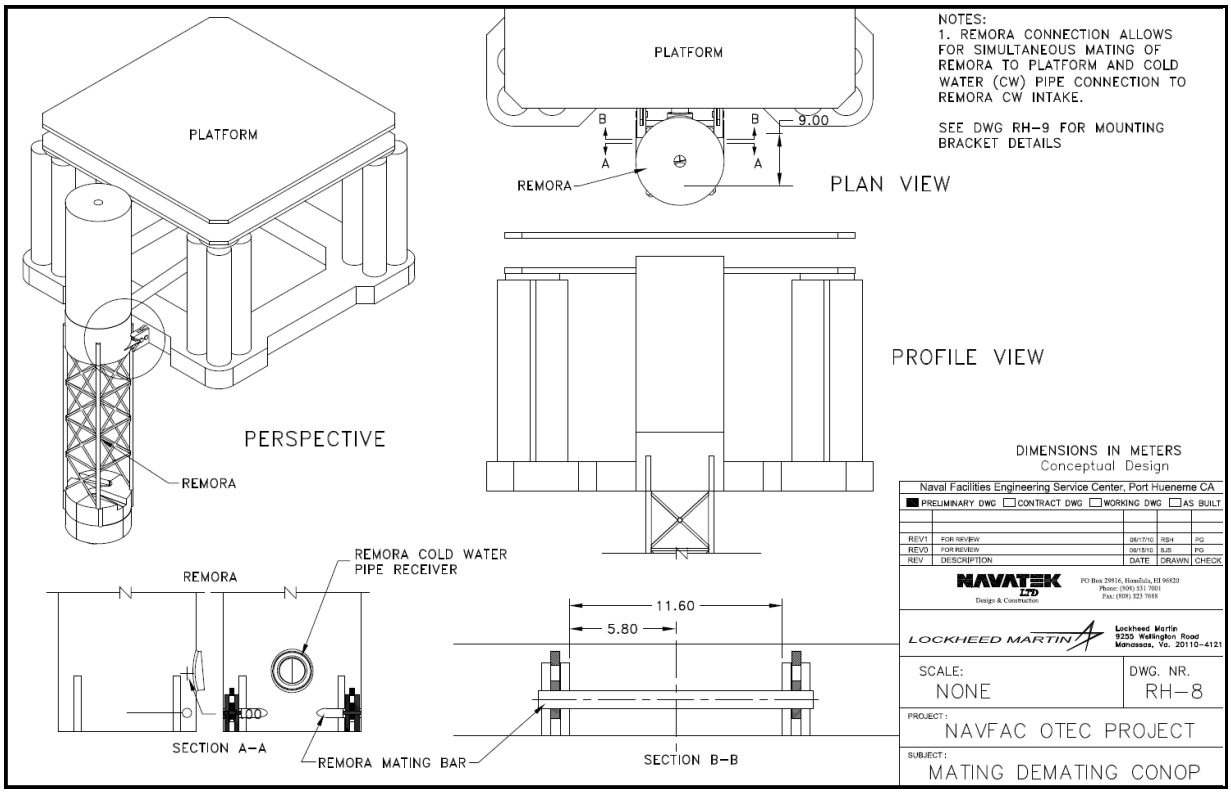


Figure 3-114. Remora Mating/Demating Procedure

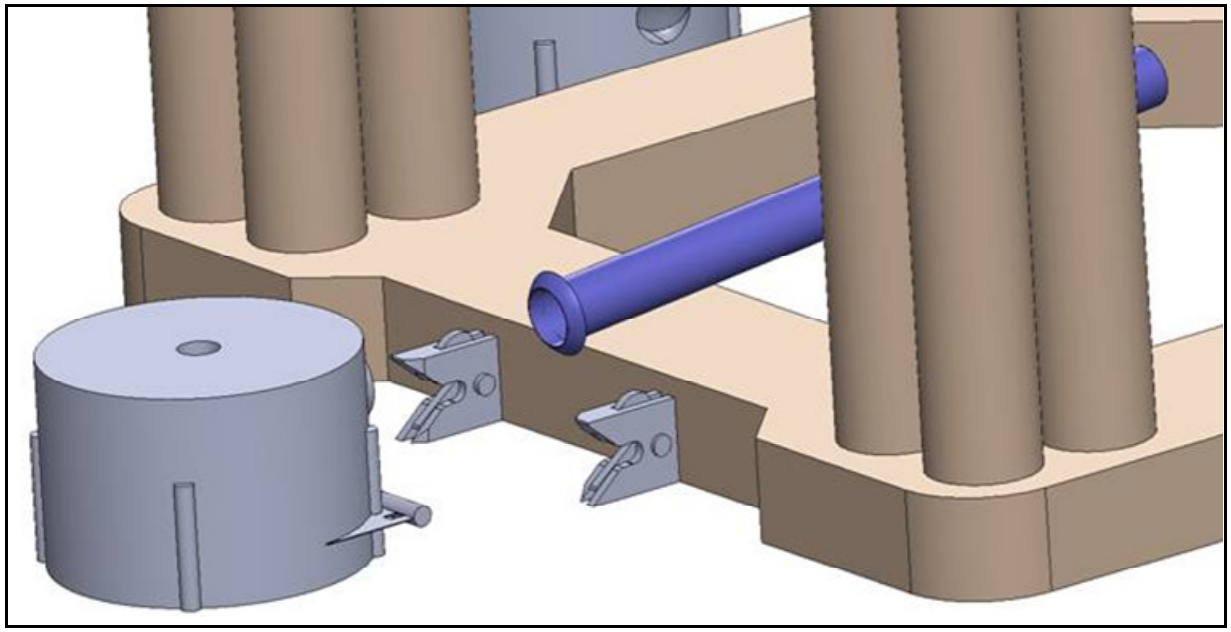


Figure 3-115. 3d Model of Remora/Platform Lower Mating Concept

The intent of the remora/platform mating process is to connect the remora at three points: an upper connection at the top of the remora; a lower connection at the bottom of the remora's hard tank and a non-structural connection between the cold water pipe on the platform and the cold water intake piece on the remora. Additional design and development is required for each aspect of the mating procedure and the mating hardware.

Generally, the remora/platform mating procedure is:

- Ensure several hours of calm seas;
- Upend the remora;
- Ballast the remora so that the cold water side leans away (at the top) from the platform;
- Haul the remora in toward the platform using sheaves mounted on the platform with pushing support from a tug;
- Engage the lower remora/platform connection;
- Engage the upper remora/platform connection (the upper connection may have to lowered on to the remora);
- Seal the cold water pipe connection.

Upper Platform Connection

The upper remora/platform connection is located between remora frames 0-4 and is illustrated in Figure 3-116. It is intended to be a pinned connection (or two pinned connections) that restrict the remora in four degrees of freedom, but not in heave (or yaw for the single connection). The remora is allowed to move in heave at this connection to account for remora and platform thermal expansion and contraction.

After the remora is mated to the platform, other systems should be interconnected. For the ammonia system, these include two 36" ammonia vapor pipes to and from the turbine, two 2" buffer vent pipes, and control and instrumentation wiring. For the electrical systems, the cold water pump, warm water pump and two ammonia pump electrical power cables need to be connected. For safety, all connections should be accomplished near or on the platform, at deck elevation. The connection to the cold water crossover duct is discussed after this section.

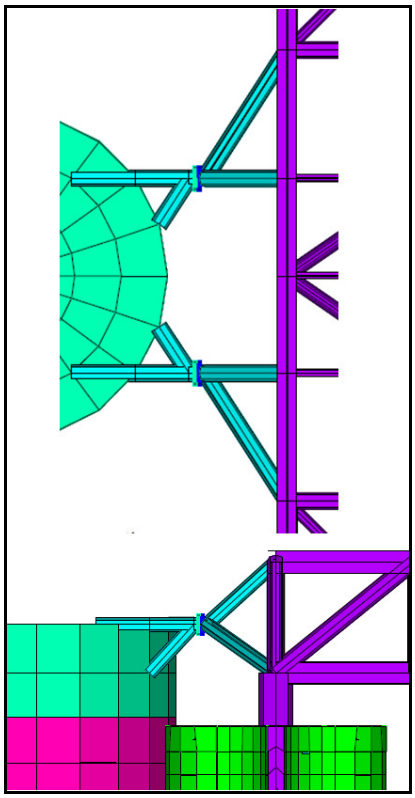


Figure 3-116. Upper Remora/Platform

Lower Platform Connection

The lower remora/platform connection is located between remora frames 36-40 and is illustrated in Figure 3-117 with additional details in Figure 3-118 and Figure 3-119. Figure 3-118 illustrates the capturing of the remora's mounting bar by the capture device mounted on the platform. Additional details of the capture device are presented in Figure 3-119. In order to slow down the possible heave and pitch motion of the remora with respect the platform a set of shock cells is proposed. Cut sheets and data on a possible set of shock cells manufactured by EPI are included in Appendix 3.3-28.

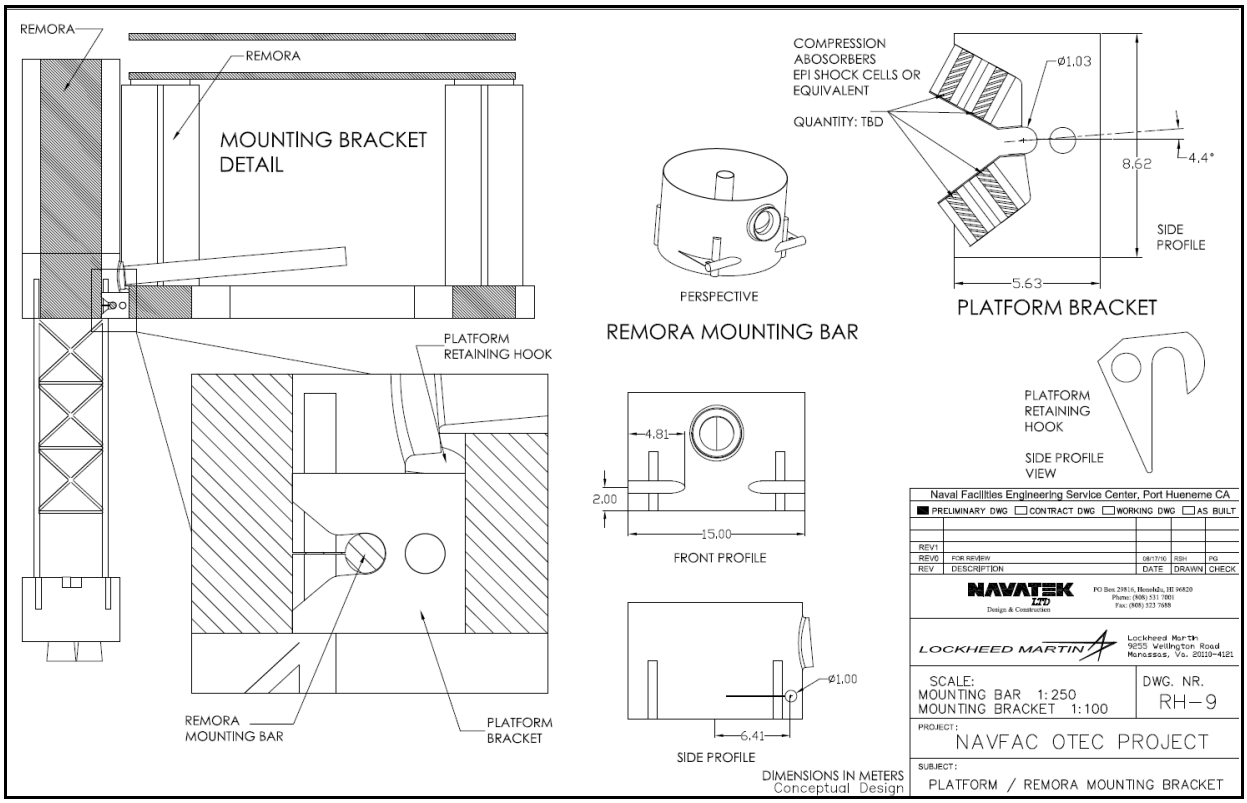


Figure 3-117. Remora/Platform Lower Connection

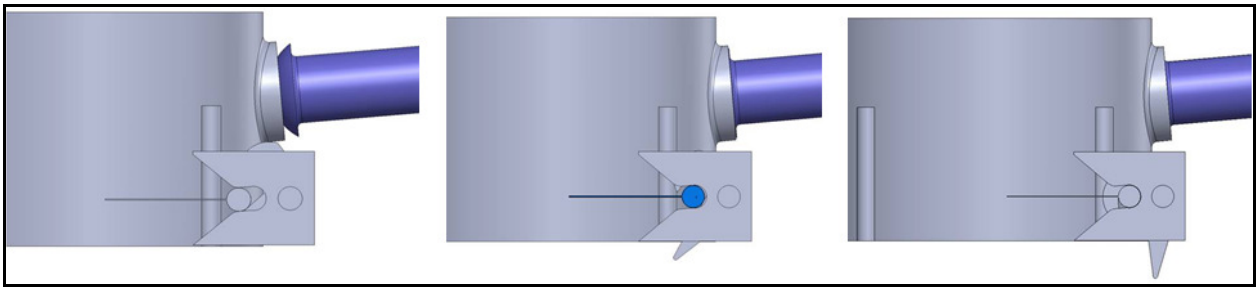


Figure 3-118. Remora/Platform Mating--Schematic of Lower Connection

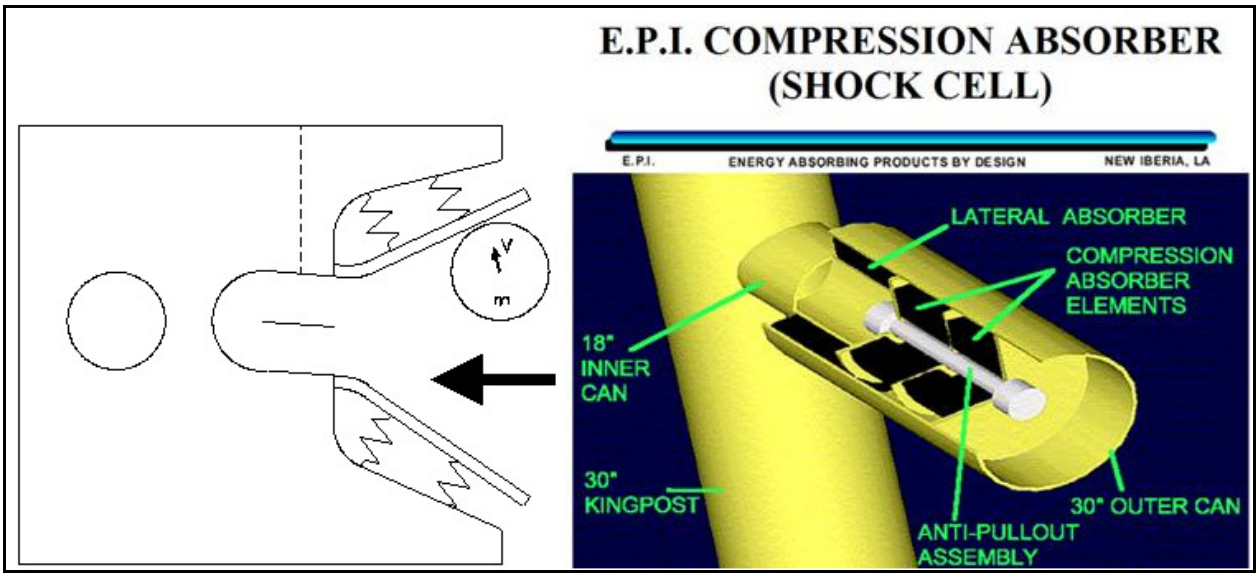


Figure 3-119. Remora/Platform Lower Connection Details

Cold Water Ducting Interface

Connecting the cold water crossover duct on the platform to the remora's cold water intake also presents a challenge. The connection must be made as part of the mating process and should be non-structural so that the cold water pipe remains isolated from the stresses resulting from relative motion between the remora and the platform. The current mating concept is illustrated in Figure 3-118 and details of the cold water pipe receptor on the remora are shown in Figure 3-120.

The intent for mating the cold water crossover duct with the cold water intake is to slow down the relative lateral velocity between the remora and platform with the shock cells illustrated in Figure 3-119 and then engage the connection bar on the remora with the capture mechanism on the platform. Once the connection bar is engaged, the top of the remora can be pulled in using the sheaves mounted at the top of the platform. As the remora top is drawn in toward the platform the cold water pipe will mate with the receptor built on to the cold water intake on the remora.

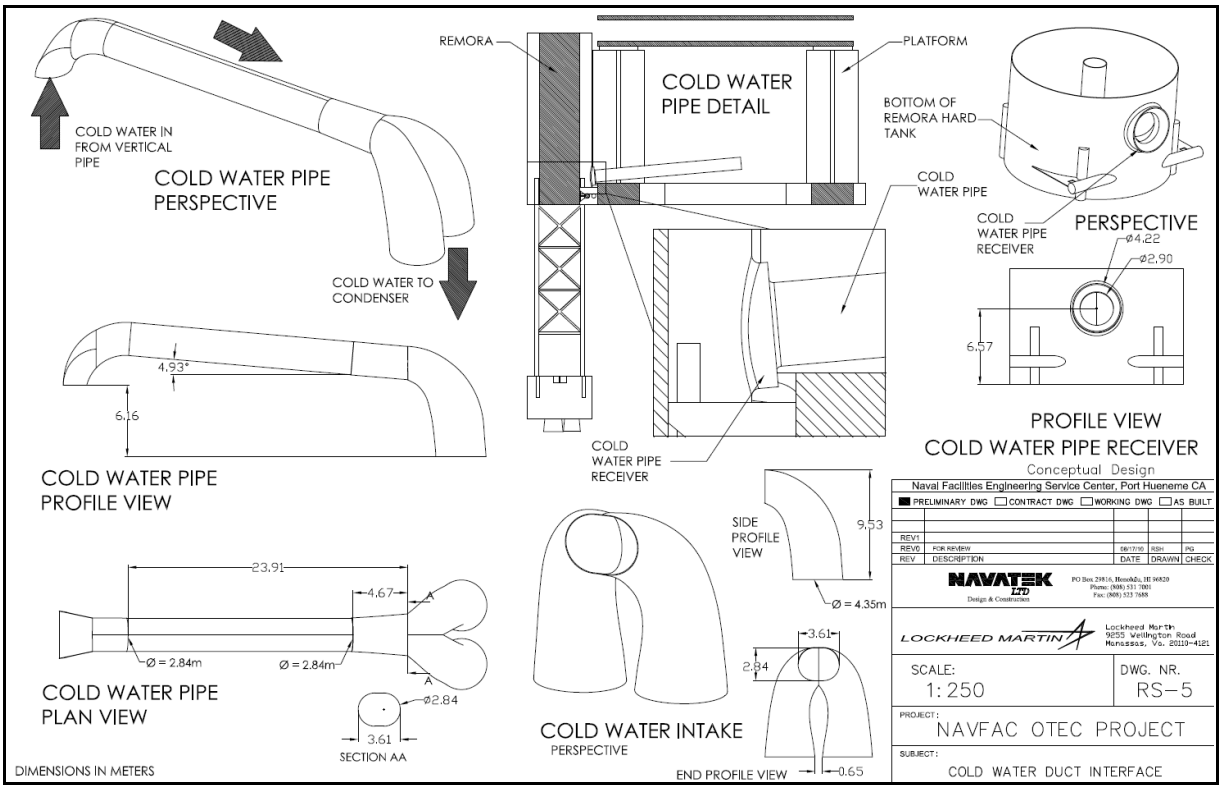


Figure 3-120. Remora/Platform Cold Water Duct Connection

3.3.2.1.1.5 Hull Corrosion Protection

The remora hull is made primarily of carbon or alloy steel and is 90m in length (70m submerged), 15m in diameter, and weighs 3400 tonnes in air. It is comprised of four watertight longitudinal bulkheads and two primary ballast tanks. For the pre-FEED design, the hull corrosion management provisions consist of a combination of protective coatings and sacrificial anodes for cathodic protection. To support the tentative remora maintenance interval, the installed anodes were sized to give a five-year life.

Corrosion protection is provided by a combination of protective coating and sacrificial aluminum anodes. The specific combination of coating and anode requirements will result from a tradeoff of cost and weight between the two selected systems. The number and weight of the anodes required for cathodic protection depends upon the selected coating material properties and thickness.

The weight and surface area of anode material required also depends on the exposed surface area to be protected and the quality of the coating used. Only the exterior portions of the steel remora hull will be protected. Internal areas such as the inside of the ballast tanks will not require either coating or cathodic protection because they will be sealed so that little oxygen is available for corrosion.

Two representative coating/cathode alternatives have been defined:

A. Alternative A: A coating meeting the requirements of DNV RP-B-401 Category II (250µm - approximately 10 mils) is used. If this coating is used, 1473 kg (3248 #) of anodes will be required. If Galvotec GA-A-1-2-H (29 # each) anodes are used, 112 anodes would be required.

B. Alternative B: A coating meeting the requirements of DNV RP-B-401 Category III (350 µm - approximately 14 mils) is used. If this coating is used, 654 kg (1443#) of anodes will be required. If Galvotec GA-A-1-2-H (29 # each) anodes are used, 50 anodes would be required.

The final combination of coating and anode distribution will be established as part of the FEED phase of the design.

Corrosion of the structure in salt water is a concern, especially for a structure that is designed for 20 years of service with minimal maintenance. For the remora, the risk of corrosion is particularly acute in the area of the truss and the cold and warm water heat exchangers where there is likely to be a mix of structural materials including steel, aluminum and possibly titanium.

- In order to address the risk of corrosion from the beginning of the design a corrosion study was performed, Appendix 3.3-29. It should be noted that this corrosion study was performed before many of the details of the remora design, such as details of the heat exchanger mountings, were completed. The corrosion protection study was done based on the assumption that the remora would be dry-docked every five years. Anode weight calculations were performed using the Det Norske Veritas (dNV) Recommended Practice for Cathodic Protection Design, DNV-RP-B401. Some of the principal conclusions from the corrosion protection study include:
- Submerged dissimilar metals should not be in contact;
- External surfaces of the remora should be painted;
- Internal surfaces of the remora need not be painted;
- Cathodic protection in the form of sacrificial anodes should be used;
- The quantity of anodes required is dependent on type of hull coatings used, as shown in Table 3-45. For the current study, it was assumed that the exterior surfaces of the remora were painted with a Category II coating.

Table 3-45. Anode Weight versus Type of Coating

Coating Category	Definition	Minimum Coating Thickness (µm)	Paint Weight (kg)	Quantity of Anodes	Weight of Anodes (kg)	Total Treatment Wt (kg)
Bare	No coating	0	0	990	13085	13085
I	1 layer epoxy coating	20	20	346	10080	10100
II	1+ layer epoxy coating	250	2463	112	4572	7035
III	2+ layer epoxy coating	350	3448	50	1473	4921

Figure 3-121 shows the arrangement of sacrificial anodes recommended by the corrosion protection study.

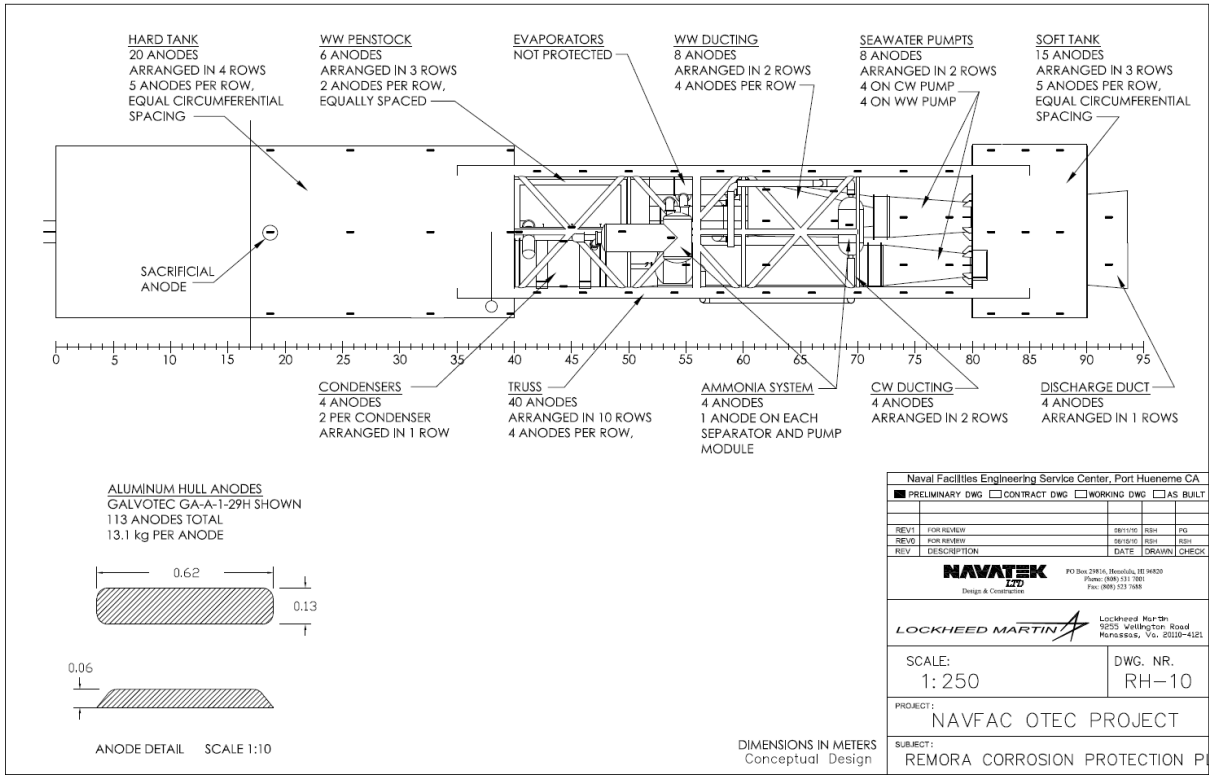


Figure 3-121. Arrangement of Sacrificial Anodes for Remora Iteration 2.1

3.3.2.1.1.6 Hull Instrument and Control

Remora hull instrumentation and control consists of twenty tank level indicators (TLIs), with corresponding high level alarms, one for each quadrant of the five void/tank decks. If water is detected in a compartment an alarm will alert the operator to the presence of water in that compartment. The operator will be responsible for determining the necessary actions in response to the water alert. If pumping is needed, a crew will open the appropriate ballast tube cover to insert a bilge pump and hose to pump the compartment. Further investigation (interior, or exterior by divers or Remotely Operated Vehicle (ROV)) will then likely be needed.

3.3.2.1.2 Working Fluid Subsystem

The following section describes the working fluid subsystem's overall modeling, and then gives details of the various components that comprise the overall system. Because OTEC is using a naturally occurring renewable resource, this discussion should begin with a discussion of that resource, and how the resource was modeled to develop an efficient and cost-effective design.

Temperature Variations

Surface seawater temperature varies hourly, daily, and from summer to winter. This variation in temperature changes the operating conditions of the power cycle. In addition, the temperature of deep seawater has slight variations that are independent of season. The first step in determining the effects of seawater temperature variation is to characterize the temperatures.

The University of Hawaii has been collecting monthly temperature profile data as part of research cruises off the west coast of Oahu since 1947. Most of the data collection has been a part of Hawaii Ocean Temperature Series (HOTS) study initiated in 1988. Since 2004, the station for data collection (known as the Kahe Station) has been located at 21° 20.6'N, 158° 16.3'W. This site is close to the proposed pilot plant installation locations and the data are expected to be representative of those sites. The data collected by the University of Hawaii was compiled and analyzed in order to determine how OTEC output would change seasonally, and is included as Appendix 3.3-30. Figure 3-122 characterizes the data that was analyzed.

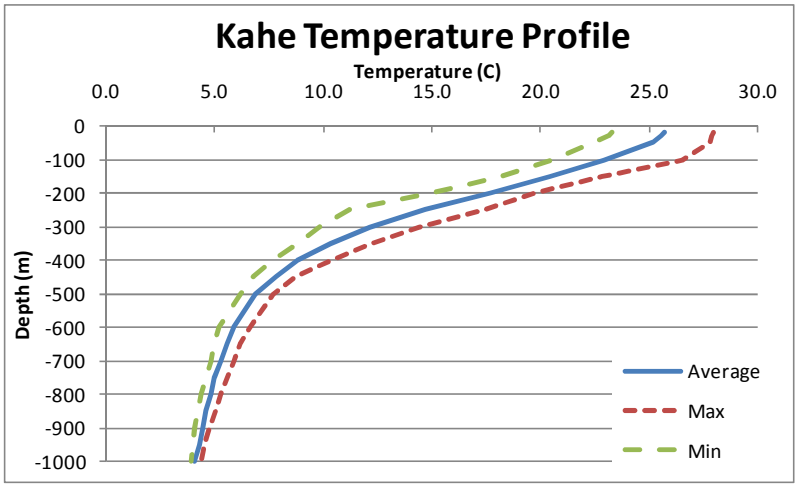


Figure 3-122. Temperature Data Collected by the University of Hawaii

The maximum and minimum temperatures shown in shallow water correspond to summer and winter temperatures respectively. The maximum and minimum temperatures at depth represent non-seasonal variation. Extreme temperature maxima and minima (shown by the dashed green and red lines in Figure 3-122) are rare events. The design maxima and minima were selected such that they are expected to be exceeded 5% of the time. These design values are shown in Figure 3-123 and Figure 3-124.

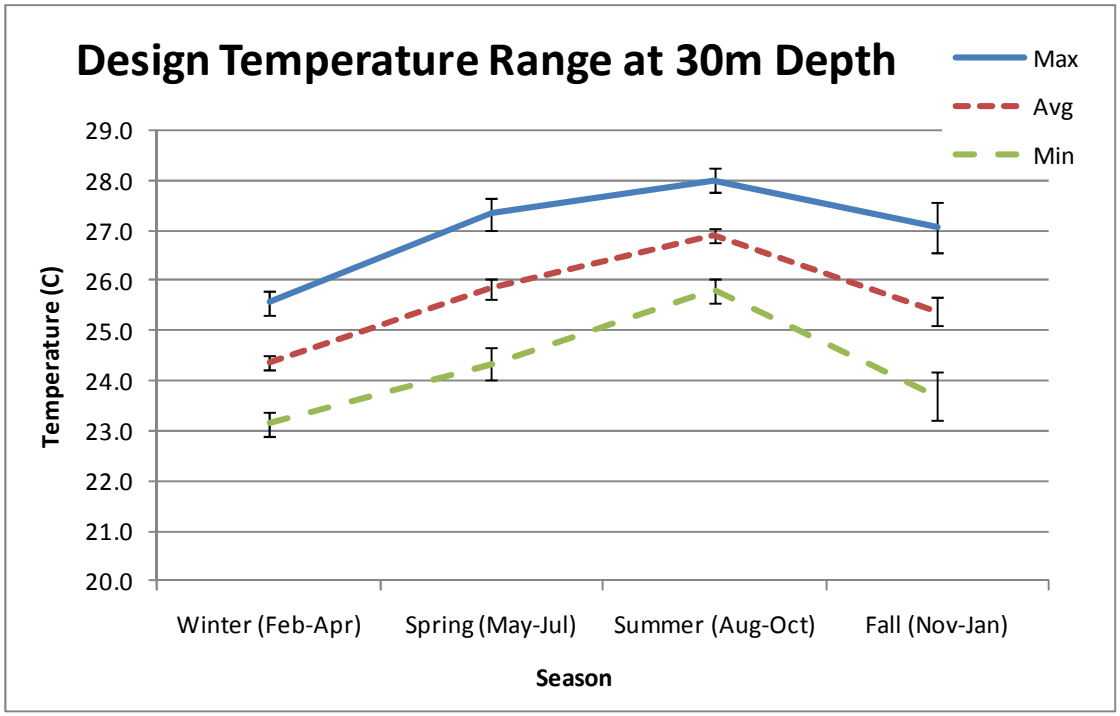


Figure 3-123. Design Temperatures 30 m Depth

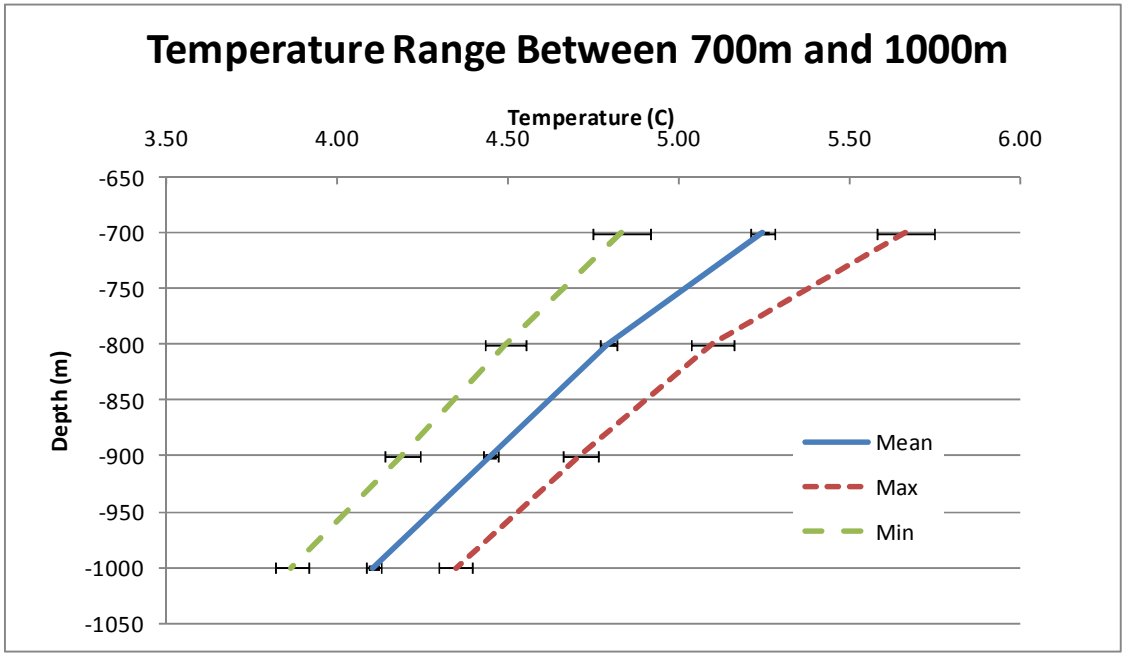


Figure 3-124. Design Temperatures between 700 m and 1000 m

The Makai OTEC Thermodynamic and Economic Model (MOTEM) was used to predict the changes in power output and the changes to the power cycle control system that would be required. The thermo-economic model has been developed over the past 5 years as an extensive model that is an invaluable tool for assessing and optimizing OTEC systems.

Model Overview

MOTEM consists of several modules, each representing a specific subsystem of a floating OTEC plant. Figure 3-125 shows an outline of the various modules that make up the model and the overall logic of the software. Each module gets inputs from, and sends outputs to, other modules. Each module has a set of user defined parametric values for relevant design variables. There is a control module where the major inputs are defined. These include the ambient water temperature and density profiles, seawater flow rates, cold water intake depth, and net electrical power output. The process is iterative with the results from the previous iteration used for the next iteration. Each module's technical output is sent to an economic module in which the user inputs component costs, book life, interest rates, and inflation rates. This module calculates the levelized cost of the product for the full life of the plant.

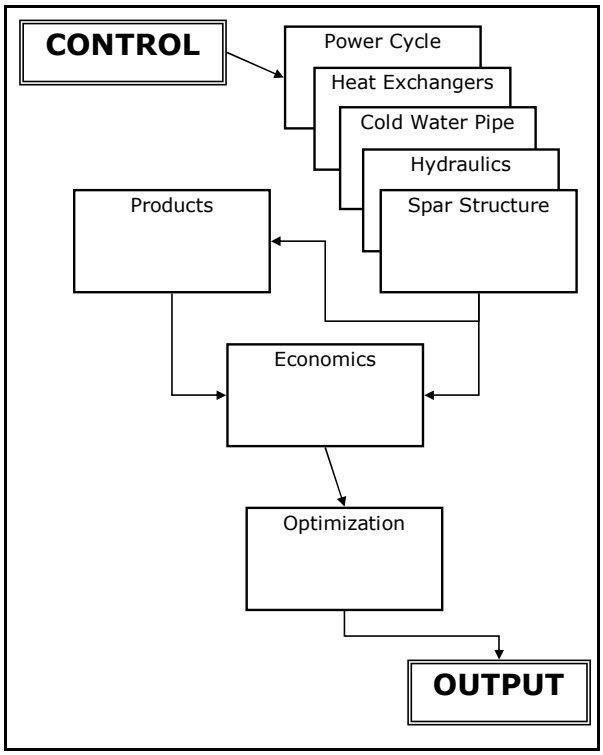


Figure 3-125. Components of Makai's Thermo-Economic Model

The basic purpose of MOTEM is OTEC economic optimization. It is important to distinguish between the thermodynamic optimum and the economic optimum. A system at its thermodynamic optimum has all of its components operating at the highest efficiency possible. However, this state is typically not the economic optimum where the system provides the lowest cost per kWh. The highest efficiency configuration is relatively easy to engineer, but developing the economic optimum is more challenging because it requires both engineering and cost data. Makai's model performs these engineering calculations, and also uses input cost data, materials cost' rules of thumb, and present value economic equations to define the economically optimized system. The model is effective at determining an economic optimum and invaluable for relative comparisons between alternative configurations. Makai uses the model to economically optimize OTEC plant designs, compare OTEC configurations, select the most cost effective components, balance thermodynamic flows, evaluate the effects of varying seawater temperatures, compare plant sizes and locations, and even assess the value of alternative products (fresh water, ammonia, hydrogen).

Application to the Pilot Plant

MOTEM is capable of static simulation of the entire power cycle; including heat exchangers, ammonia piping, ammonia pumps, and the turbine. Additionally, it models seawater hydraulics; including the cold water pipe, heat exchangers, seawater ducting, and seawater pumps. These two capabilities allow the model to determine the thermodynamic state and mass flow rates at each point through the power cycle.

The general pilot plant configuration is based on annual average seawater temperatures. This approach selects seawater flows, heat exchanger areas, and pump sizes to maximize annual average power output. However, turbine operating conditions (and therefore heat exchanger operating conditions) can be varied with seawater temperature to maximize daily power output. Turbine operating conditions can be adjusted such that evaporator and condenser pressures are maintained at setpoints that maximize electrical power output. This capability was captured by MOTEM's optimization features. Average and extreme summer/winter seawater temperatures were entered into the model, heat exchanger areas and seawater flow rates were fixed, and the model was allowed to determine what turbine operating conditions allowed the maximum possible electricity production. The results of the analysis are shown in Figure 3-126 and Table 3-46.

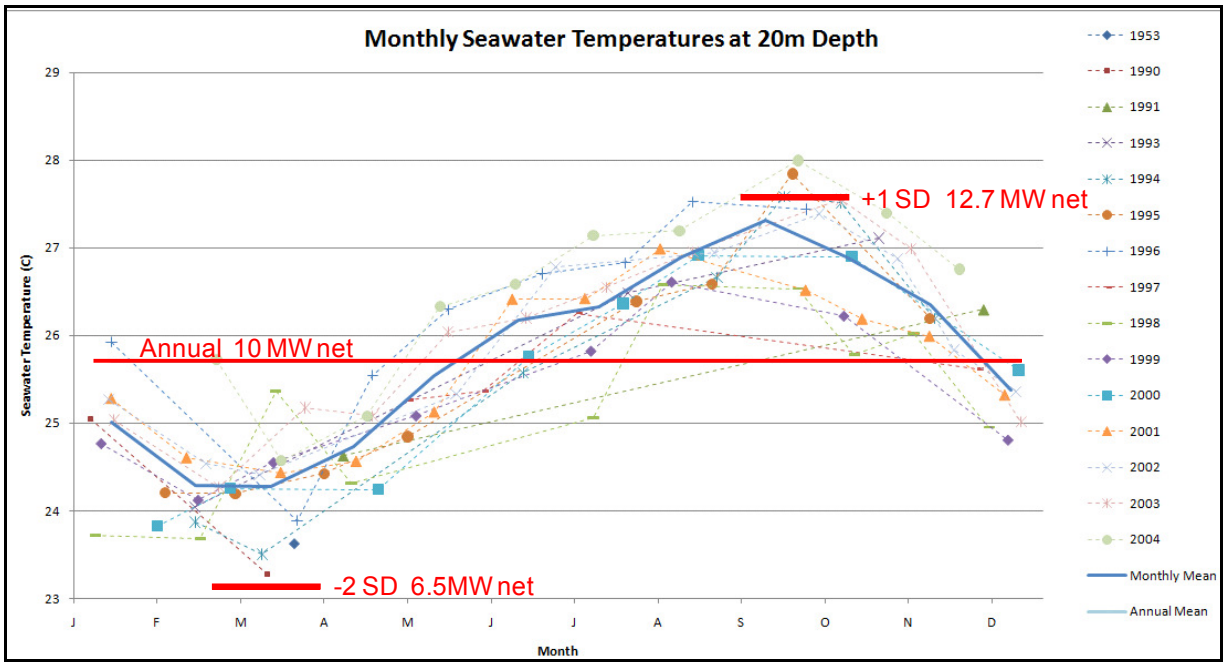


Figure 3-126. Seasonal seawater temperatures with maximum & minimum power production

Table 3-46. Seasonal Power Production Cases Considered

Case	WW Temp [C]	CW Temp [C]	SW dT [C]	Gross Power [MW]	Net Power [MW]	Ammonia Flow Rate [kg/s]	Evaporator Outlet Temp [C]
Avg + 2SD Summer	28.2	3.86	24.3	18.11	13.51	651.3	22.9
Avg +1SD Summer	27.6	3.86	23.7	17.29	12.72	650.3	22.3
Average Summer	27.0	4.11	22.9	16.17	11.65	627.5	21.9
Baseline	25.7	4.11	21.6	14.44	10.00	625.0	20.6
Average Winter	24.4	4.11	20.3	12.70	8.34	622.6	19.3
Avg -2SD Winter	23.1	4.35	18.8	10.75	6.47	587.7	18.3

Pilot plant power output will vary seasonally between 6.5 MW and 12.7 MW. The lower value is based on simultaneous minimum surface water temperature and maximum deep water temperature, and is expected to be an extreme minimum. The average winter output of the pilot plant is expected to be 8.3 MW. The maximum power output of the pilot plant (12.7 MW) is fixed by turbo-generator size. It is not cost effective to size the turbine and generator for the most extreme (and therefore rare) temperatures expected. Instead, the maximum plant output was selected as that which would be exceeded 33% of the time. The average summer output of the pilot plant is expected to be 11.7 MW.

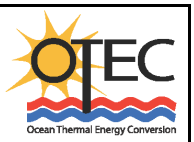
Working Fluid

The OTEC system uses anhydrous ammonia (R-717) in the working fluid subsystem. Ammonia gas and liquid have high thermal conductivities and high heat capacities relative to most other refrigerants. This combination of attributes makes ammonia an excellent heat transfer fluid. Because it is widely used, there is a well-established industry base for code application and component suppliers. It is ozone friendly, and is not a greenhouse gas. For the convenience of the reader, Appendix 3.3-40 provides thermodynamic properties of ammonia.

Refrigeration grade ammonia is 99.95% pure, with the impurities generally being oil and water. It is compatible with steel, stainless steel, aluminum and titanium, except that high-strength steels may experience stress corrosion cracking. Ammonia is incompatible with copper, zinc, or copper-based alloys, (although some oil-coated copper-based bearings are used successfully). These properties of course influence the design and materials of the heat exchangers and other components. A list of the key decisions and studies for the working fluid subsystem is shown in Figure 3-127. Of these first items, the evaporator details will be discussed within the warm water section, and the condensers will be discussed within the cold water section.

The remaining key trade decision was to design the OTEC system to be only a single cycle. This decision allowed use of only one turbine and a simpler control system, albeit it will use slightly larger heat exchangers than a dual-stage cycle. The three Design decisions listed flow logically from the remora requirement stated earlier that the heat exchangers would be submerged in seawater. This decision vastly simplifies the ventilation and safety requirements for the ammonia system, and improves the seawater duct arrangement, but imposes the need to use extremely reliable valves, pumps and instruments where submerged.

Working Fluid Subsystem - Design Decisions Key Design Trades Summary



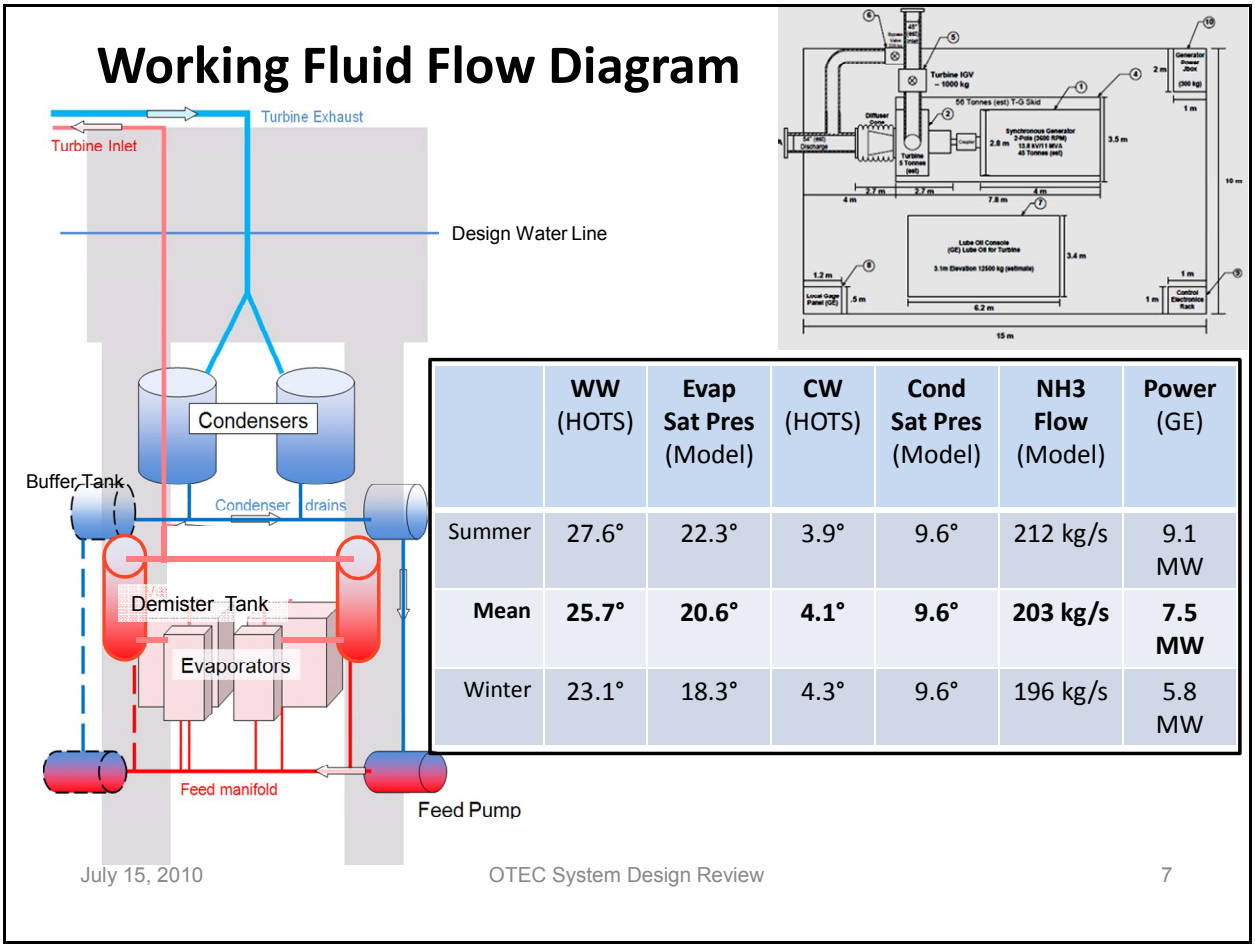
Trades	Results and Rationale
Evaporator Type - Extruded Brazed Aluminum HX	High performance, Corrosion, Cost,
Condenser Type – Steel Shell & Ti Twisted Tube	Good performance, Pitting resistance, Cost,
Single Stage Cycle	Single turbine, pump, controls

Design Decisions	Results and Rationale
Submerged Ammonia components	Simplify ventilation when inspecting or replacing rotating machinery. Assumes very reliable valves
Standard NH3 pump in sealed pod	Easiest to develop.
Submerged Instrumentation	Necessary evil. Minimize these. Oceanographic style.

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Figure 3-127. Major Design decisions of Working Fluid Subsystem

The location of the ammonia pumps, buffer tanks, and demister vessels are shown in Figure 3-128. The figure also presents the seawater temperature, evaporator temperature, condenser temperature, ammonia flow rate and power generated for the three conditions, including the source of each value. After the components have been described, a detailed description of the cycle is presented in Figure 3-136. A cycle diagram showing temperature and mass flows for a 10 MW system is presented in Figure 3-137.



	WW (HOTS)	Evap Sat Pres (Model)	CW (HOTS)	Cond Sat Pres (Model)	NH3 Flow (Model)	Power (GE)
Summer	27.6°	22.3°	3.9°	9.6°	212 kg/s	9.1 MW
Mean	**25.7°**	**20.6°**	**4.1°**	**9.6°**	**203 kg/s**	**7.5 MW**
Winter	23.1°	18.3°	4.3°	9.6°	196 kg/s	5.8 MW

Figure 3-128. Major components and parameters of ammonia system

3.3.2.1.2.1 Working Fluid Pumps

The design uses commercially available magnetically coupled ammonia pumps housed in a sealed steel pressure-capable "pod" that can be submerged to 60 meters deep. Each remora contains two 100% redundant pumps. At sea, one pod can be operating while the other is removed, brought to the surface for maintenance or repair, and then re-installed by divers. The piping system is fitted with two-valve-protection and appropriate vacuum ports to enable this procedure.

The benefit of a magnetically coupled pump is that the ammonia working fluid is contained within a static, non-rotating, hermetic seal, and thus will not lose ammonia into the pod's interior. Figure 3-129 shows the internal features, but not the motor, of a magnetically-coupled pump. The pump curve used for the design, available as a 250 horsepower pump from Dickow Pumps, is shown in Figure 3-130.

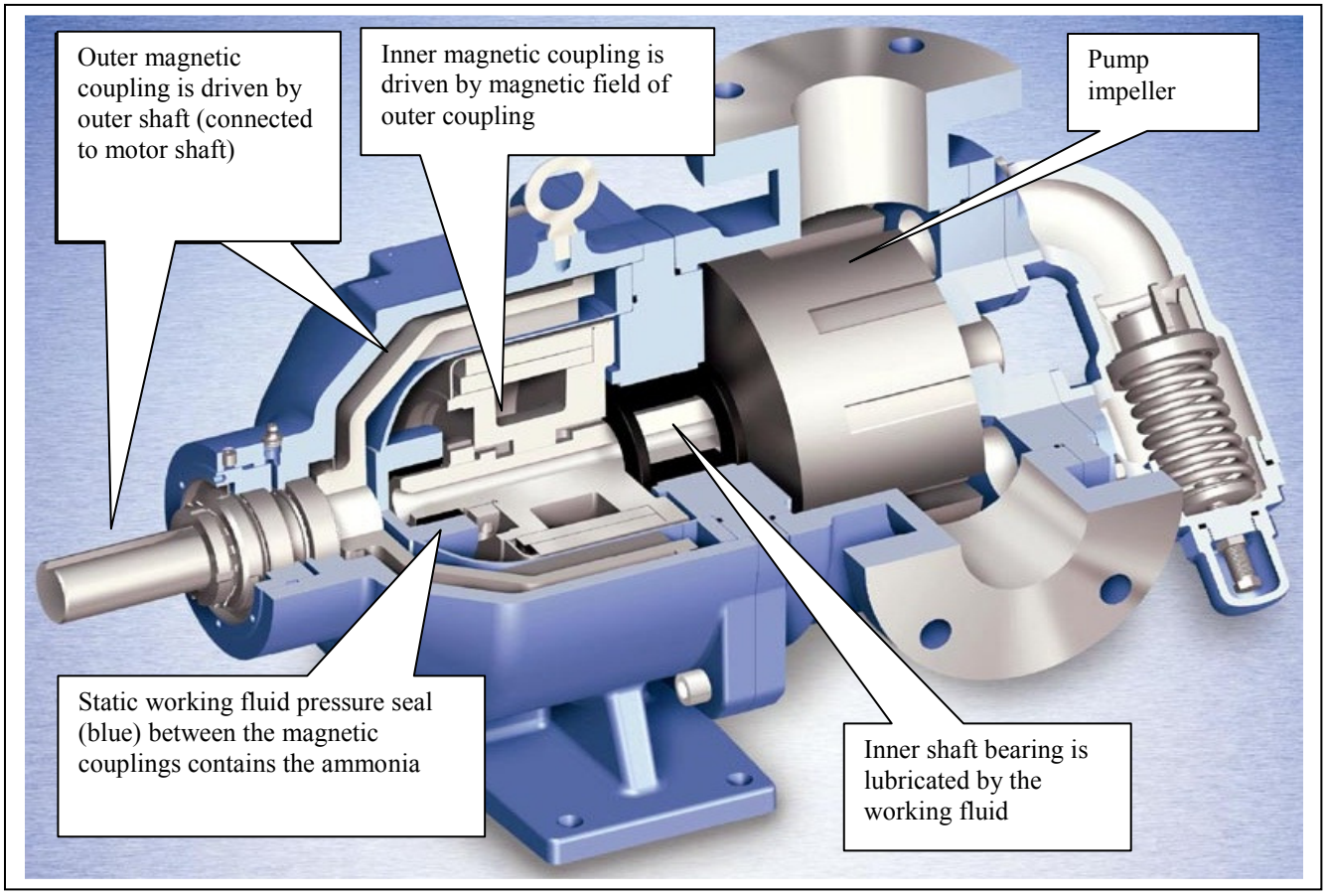


Figure 3-129. Web illustration of a magnetically coupled pump

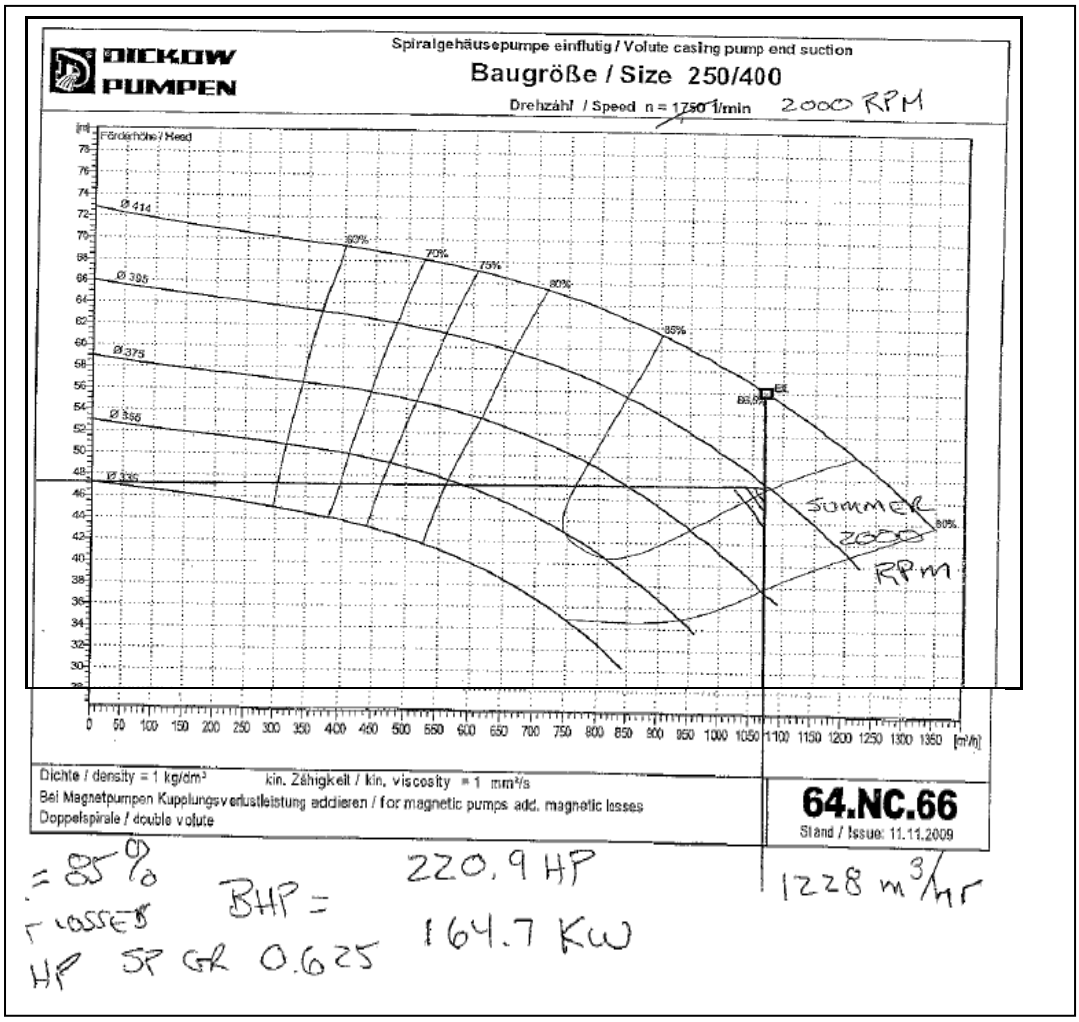


Figure 3-130. Pump Curve for Dickow 12″ x 10″ x 15.5″ NH3 pump

Figure 3-131 illustrates the arrangement of the ammonia pump within the pump pod. The interfaces between the pod and the remora consist of the pod mounting foundations, the power and instrument cables, and the ammonia inlet and outlet flanges. Within the pod itself, both ammonia flanges will use expansion joints to make up for slight misalignments between the pod piping and the pump flanges. The standard pump foundation will probably have resilient mounts for sound isolation and fatigue prevention, if so then movement should also be limited to prevent fatiguing the ammonia flanges from wave-induced motions. These details can be completed during FEED. It is recommended that the pod contain an ammonia sensor to detect leaks, otherwise an undetected ammonia leak may damage the motor windings. It should also be considered if charging the pod's interior with nitrogen is a useful method to prevent fires and corrosion.

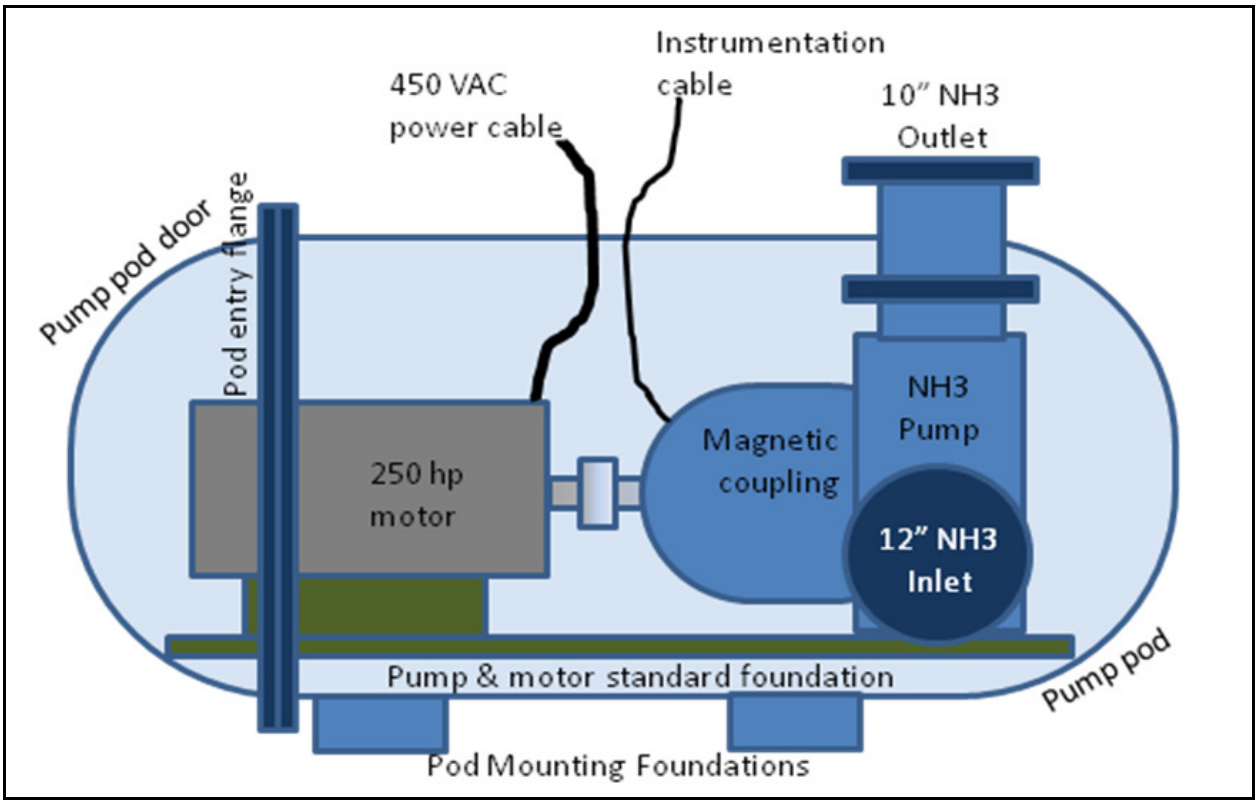


Figure 3-131. Arrangement of NH3 pump within 1.2m dia x 2.9m long pump pod

3.3.2.1.2.2 Working Fluid Pressure Vessels



Figure 3-132. Demister tank (Image by OrbitIndustries)

A photograph of a typical demister tank used by the chemical process industry is shown in Figure 3-132. The dimensions and internal configuration of the two demister vessels for this plant are shown in Figure 3-133. The vessel has been sized to have typical velocities for chemical process tanks as described in Perry's Chemical Engineering Handbook. It must be rated to a maximum internal pressure of 1556 kPa, corresponding to a 40°C ammonia saturation temperature as per ASME B31.5. The tank must also be rated to withstand an external differential pressure of 5.5 bar, which can occur whenever the ammonia system is evacuated and the tanks are submerged at their normal depth.

As drawn, each tank is fabricated from standard 2.44 meter diameter pipe with ASME 80-20 toroidal heads. Ammonia vapor and liquid enters each demister from three 18" pipes. Each pipe has six 12" ports and a lower liquid port, allowing the ammonia liquid to heavier ammonia liquid to separate from the vapor. The liquid collects and drains from the bottom 12" port, while the vapor passes through the large conical wire mesh pads and exits the vessel though the top 30" flange.

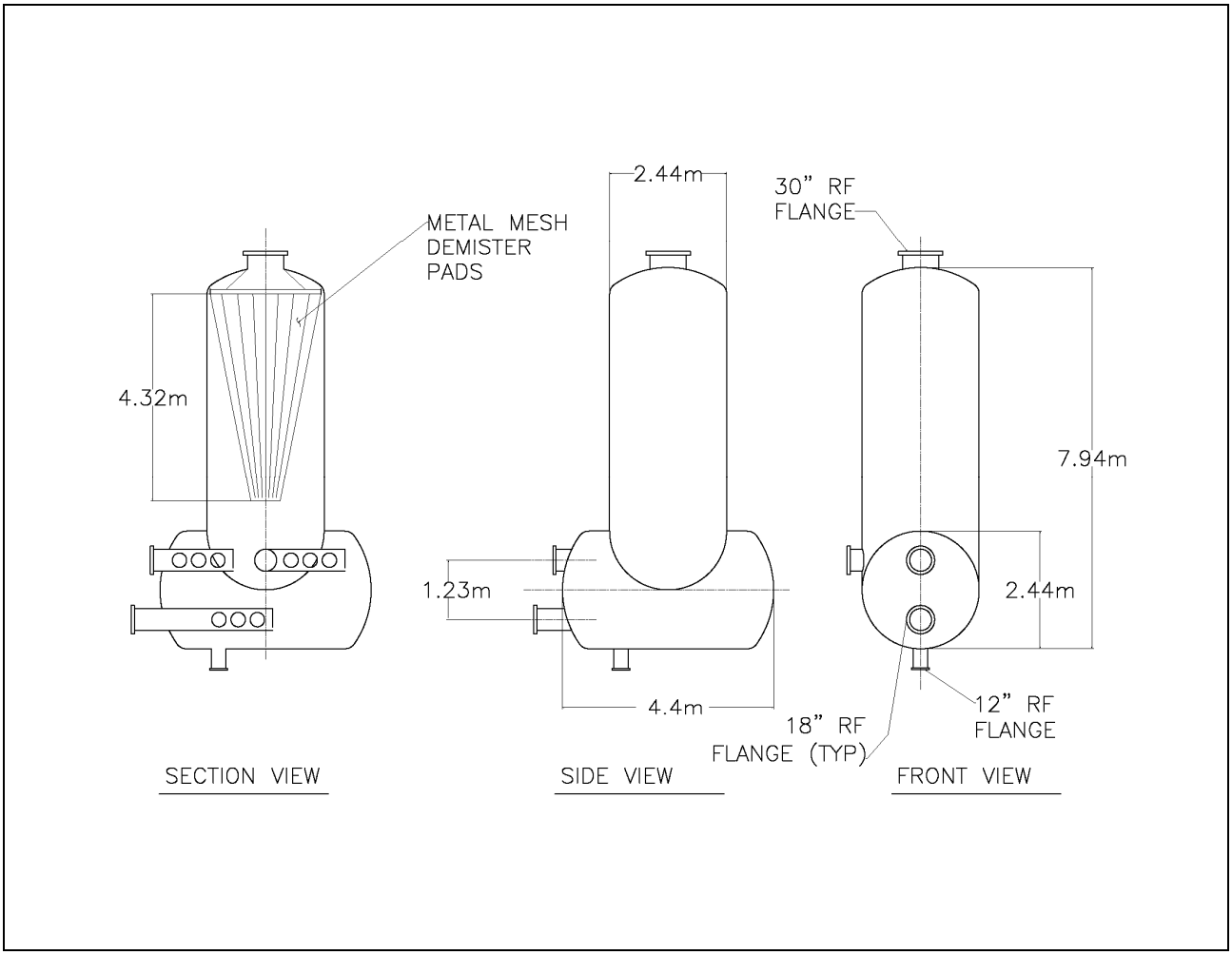


Figure 3-133. Demister tank dimensions

Each of the two buffer tanks is located adjacent to and slightly below its corresponding condenser. Each is a 3m diameter by 4m tall steel pressure vessel with external insulation and shall be rated to a maximum internal pressure of 1556 kPa. The tanks have adequate capacity to contain the entire volume of working fluid when the plant is not operating, including the 15 percent margin required by ASME B31.5. The tank must also be rated to withstand an external differential pressure of 5.5 bar. (Although ASME B31.5 allows a lower pressure, corresponding to a 27°C ammonia saturation temperature for water cooled condensers, the high external pressure requirement will likely govern the design.)

3.3.2.1.2.3 Working Fluid Storage

Three (or four, depending on tank size) uninsulated storage tanks will be located on the platform to permit simultaneous storage of all ammonia removed from both remoras. This is a requirement from ASME B31.5, and has implications for platform stability, which has been included. Suitable ammonia tanks, with pumps, valves and fittings, are readily available from the agricultural ammonia storage industry.

3.3.2.1.2.4 Working Fluid Piping and Instrumentation

Standard ammonia components can be obtained in black steel in sizes up to 6" for most components, and up to 18" for shut-off valves. Typical suppliers for these components include Hansen and Rego, and they would be suitable for use on the platform's transfer piping. For submerged applications requiring more corrosion-resistant alloys, or for sizes up to 48", suitable class 300 valves can be obtained from Bray International Inc. Excerpts from a Bray data sheet are shown in Figure 3-134. A selection of Hansen ammonia equipment is presented in Figure 3-135. Piping sizes are given in the Piping and Instrumentation diagram later in this section.

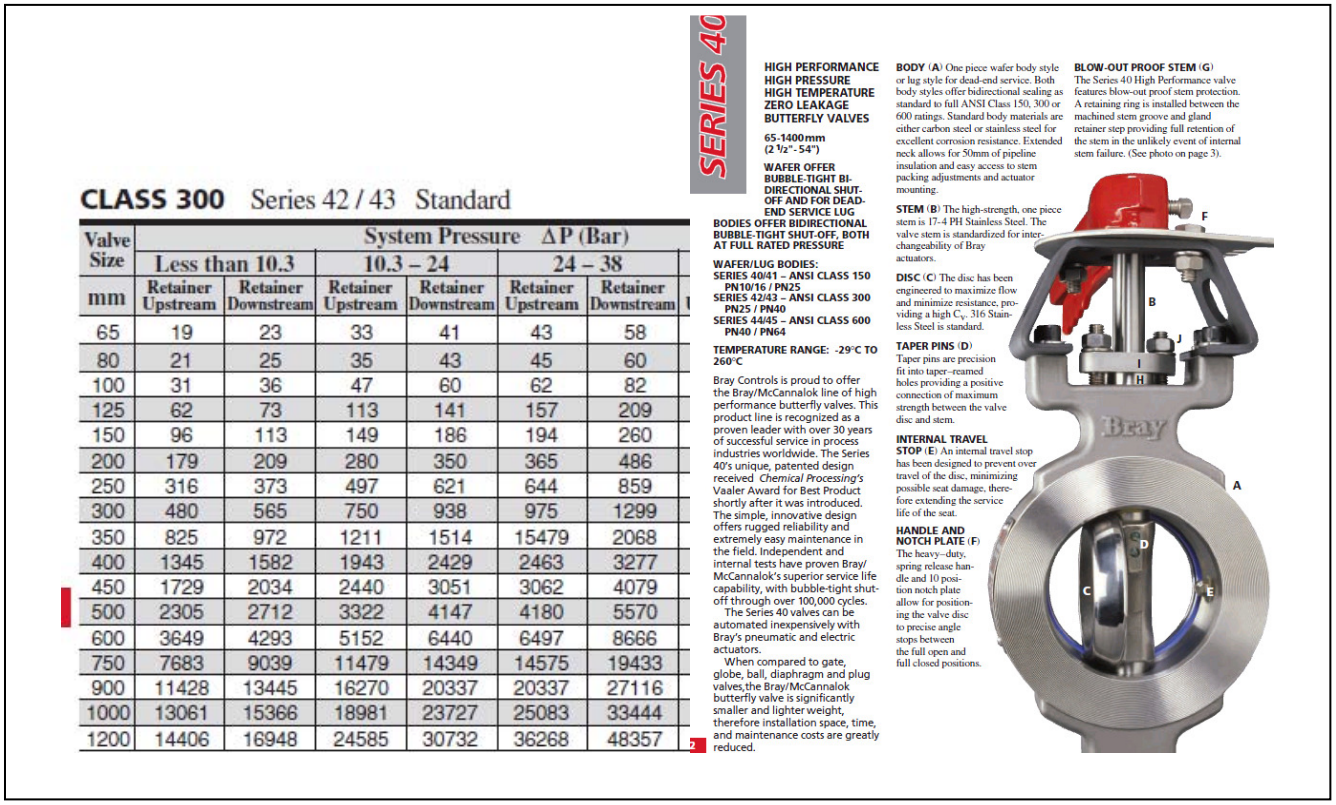
An instrument list of 118 instruments for the ammonia system and both seawater systems, including their location and suggested ranges, is included within Appendix 3.3-31.

During annual average conditions, a description of the working fluid flow path through the piping system shown on Figure 3-136 is as follows:

Ammonia liquid (203 kg/sec at 9.5°C) enters the ammonia pump and is pressurized (letter A) to more than 957 kPa. This fluid then passes through the high speed nozzle of an educator, (letter B) entraining another 109 kg/sec of warm (20.5°C) ammonia from the demister tank.

This mix (312 kg/sec at 13.4°C) enters one of the six evaporators (letter C) where 65% of it boils to vapor at 20.5°C, while the remainder stays as liquid at the same temperature. (Letter D). This 872 kPa fluid / vapor mix enters a demister vessel (letter E), where it decelerates and the liquid falls to the bottom either by gravity, centrifugal force, or impact with the fabric mesh, -then dripping to the bottom. This warm liquid ammonia (letter F) is remixed with cold incoming feed ammonia. The demister level control is regulated by the recirc valve controller.

The ammonia vapor that passed through the steel mesh exits the top of the demister vessel at 867 kPa (letter G) and then travels upward, above sea level and to the top deck of the remora. This section of piping has flanged connections for when the remora is mated or demated to the platform (letter H). The vapor is now within the platform's ammonia piping system.



CLASS 300 Series 42 / 43 Standard

Valve Size	System Pressure ΔP (Bar)					
	Less than 10.3		10.3 – 24		24 – 38	
mm	Retainer Upstream	Retainer Downstream	Retainer Upstream	Retainer Downstream	Retainer Upstream	Retainer Downstream
65	19	23	33	41	43	58
80	21	25	35	43	45	60
100	31	36	47	60	62	82
125	62	73	113	141	157	209
150	96	113	149	186	194	260
200	179	209	280	350	365	486
250	316	373	497	621	644	859
300	480	565	750	938	975	1299
350	825	972	1211	1514	15479	2068
400	1345	1582	1943	2429	2463	3277
450	1729	2034	2440	3051	3062	4079
500	2305	2712	3322	4147	4180	5570
600	3649	4293	5152	6440	6497	8666
750	7683	9039	11479	14349	14575	19433
900	11428	13445	16270	20337	20337	27116
1000	13061	15366	18981	23727	25083	33444
1200	14406	16948	24585	30732	36268	48357

SERIES 40

HIGH PERFORMANCE HIGH PRESSURE HIGH TEMPERATURE ZERO LEAKAGE BUTTERFLY VALVES

65-1400mm (2 ½" - 54")

WAFER OFFER BUBBLE-TIGHT BI-DIRECTIONAL SHUT-OFF AND FOR DEAD-END SERVICE LUG BODIES OFFER BIDIRECTIONAL BUBBLE-TIGHT SHUT-OFF, BOTH AT FULL RATED PRESSURE

WAFER/LUG BODIES:
SERIES 40/41 – ANSI CLASS 150 PN10/16 / PN25
SERIES 42/43 – ANSI CLASS 300 PN25 / PN40
SERIES 44/45 – ANSI CLASS 600 PN40 / PN64

TEMPERATURE RANGE: -29°C TO 260°C

Bray Controls is proud to offer the Bray/McCannalok line of high performance butterfly valves. This product line is recognized as a proven leader with over 30 years of successful service in process industries worldwide. The Series 40's unique, patented design received *Chemical Processing*'s Vaaler Award for Best Product shortly after it was introduced. The simple, innovative design offers rugged reliability and extremely easy maintenance in the field. Independent and internal tests have proven Bray/McCannalok's superior service life capability, with bubble-tight shut-off through over 100,000 cycles.

The Series 40 valves can be automated inexpensively with Bray's pneumatic and electric actuators.

When compared to gate, globe, ball, diaphragm and plug valves, the Bray/McCannalok butterfly valve is significantly smaller and lighter weight, therefore installation space, time, and maintenance costs are greatly reduced.

BODY (A) One piece wafer body style or lug style for dead-end service. Both body styles offer bidirectional sealing as standard to full ANSI Class 150, 300 or 600 ratings. Standard body materials are either carbon steel or stainless steel for excellent corrosion resistance. Extended neck allows for 50mm of pipeline insulation and easy access to stem packing adjustments and actuator mounting.

STEM (B) The high-strength, one piece stem is 17-4 PH Stainless Steel. The valve stem is standardized for inter-changeability of Bray actuators.

DISC (C) The disc has been engineered to maximize flow and minimize resistance, providing a high C_v. 316 Stainless Steel is standard.

TAPER PINS (D) Taper pins are precision fit into taper–reamed holes providing a positive connection of maximum strength between the valve disc and stem.

INTERNAL TRAVEL STOP (E) An internal travel stop has been designed to prevent over travel of the disc, minimizing possible seat damage, therefore extending the service life of the seat.

HANDLE AND NOTCH PLATE (F) The heavy–duty, spring release handle and 10 position notch plate allow for positioning the valve disc to precise angle stops between the full open and full closed positions.

BLOW-OUT PROOF STEM (G) The Series 40 High Performance valve features blow-out proof stem protection. A retaining ring is installed between the machined stem groove and gland retainer step providing full retention of the stem in the unlikely event of internal stem failure. (See photo on page 3).

Figure 3-134. Bray Series 40 Butterfly Valve size & opening torque



Figure 3-135. Hansen Shut-off valve, Auto-Purger, and pressure relief valves

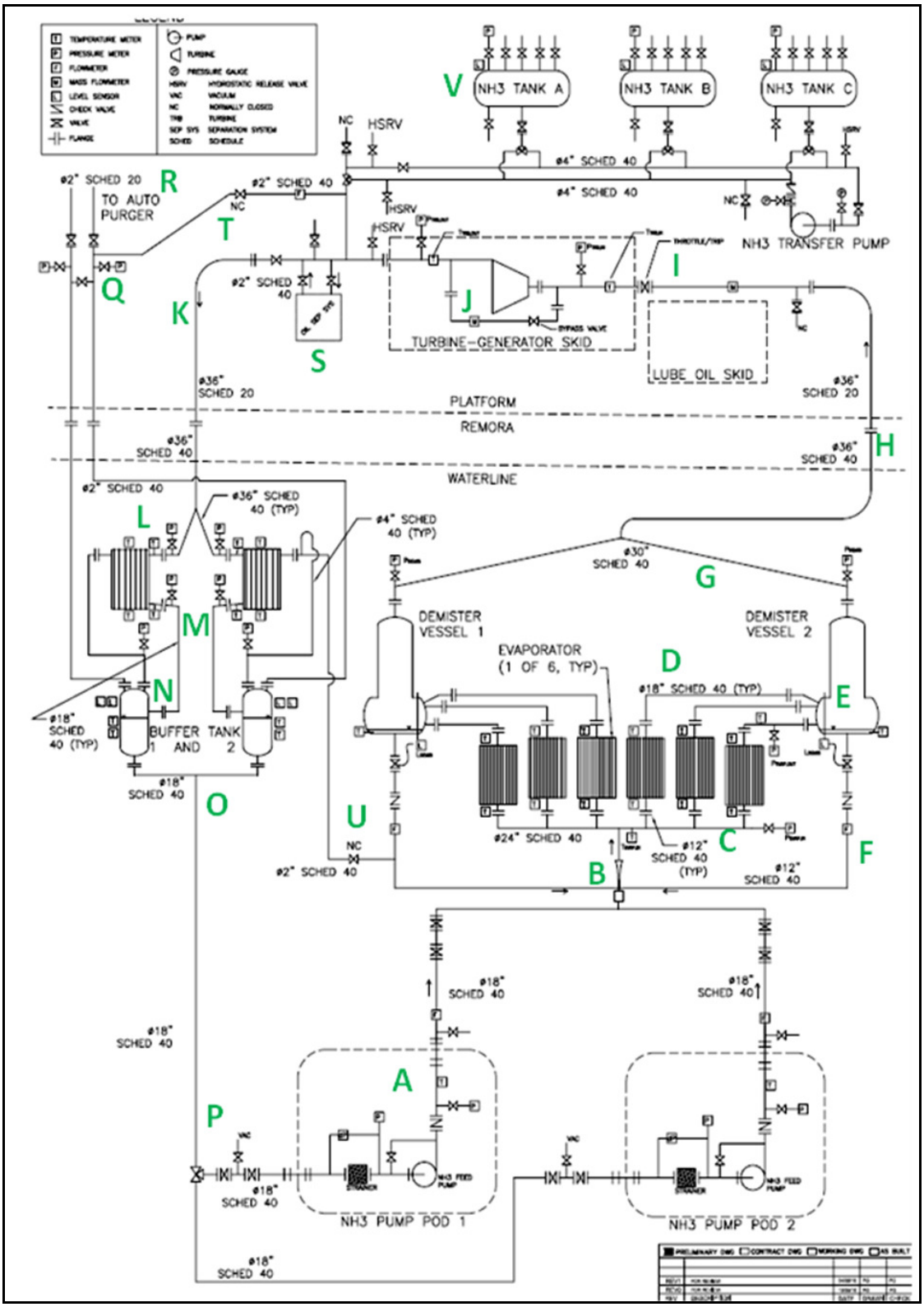


Figure 3-136. Ammonia System Piping & Instrumentation Diagram

The vapor then passes the throttle / trip valve (letter I). Most of this 864 kPa vapor drives the turbine, or a small fraction may bypass the turbine (letter J) as regulated by the turbine governor for speed control. The vapor gives up 7701 kJ of energy per second and leaves the turbine as 606 kPa, 9.6°C vapor at 97.6% quality.

The turbine exhaust flows through another flanged section (letter K), leaves the platform piping and reenters the remora piping. It travels down into one of the two condensers (letter L) where it is condensed to liquid at 604 kPa at 9.5°C (letter M). The liquid ammonia drains by gravity into the buffer tank (letter N) as a saturated liquid with very little subcooling.

Both buffer tanks share a common liquid line (letter O) and a common vapor line (near valve Q) and are located 13m above the ammonia feed pump. This elevation causes the 9.5°C liquid ammonia to be in a compressed state (683 kPa) providing adequate net positive suction head as it enters the three-way valve (letter P) and then into NH3 Pump 1 or Pump 2's ammonia strainer and pump inlet, completing the cycle. (letter A)

Other features of the ammonia piping diagram are:

A buffer purging device to vent off noncondensable gases from the buffer (letter R). Adequate purging has a significant effect upon cycle efficiency. The presence of noncondensable gases can be detected when the ammonia buffer pressure is higher than its corresponding ammonia saturation temperature.

An ammonia-oil separator (letter S) to remove oil from ammonia via a distillation process. This equipment is needed because trace quantities of oil enter the ammonia fluid at the turbine bearing mechanical seal. Over time, this oil may coat the heat exchangers and decrease cycle efficiency.

A small makeup ammonia line with a flowmeter (letter T) is needed to occasionally replenish the working process ammonia with small amounts of new ammonia from the storage tank (letter V). This periodic task replaces the ammonia lost during the purging process. A pump will not be needed because the storage tanks are at higher pressure than the buffer tanks.

Another ammonia line connects the demister liquid tank with the top of the condenser (letter U). This line may be necessary if turbine/evaporator interaction results in excess warm liquid in the demister. As before, a pump will not be needed because the demister vessels are at higher pressure than the condensers.

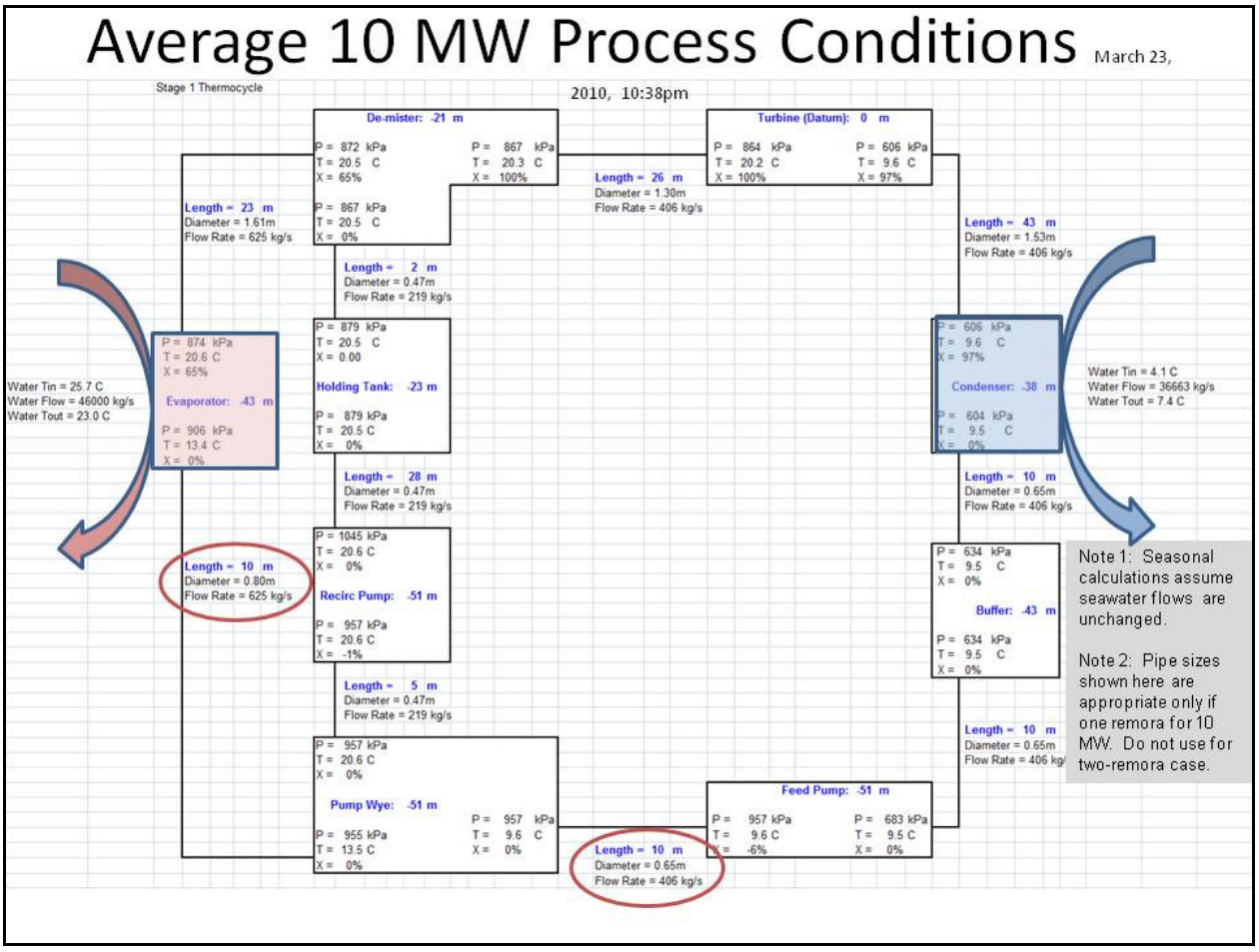


Figure 3-137. Optimized 10 MW average annual process conditions calculated by MOTEM

3.3.2.1.2.5 Working Fluid Instrument and Control

The instrumentation for the working fluid subsystem consists of temperature, pressure, flow, and liquid level sensors, as shown on Figure 3-136. A detailed instrument list is provided within Appendix 3.3-32.

As part of this work, Lockheed Martin modelers began development of a time-domain dynamic model of the OTEC system. The controls for the time-domain working fluid subsystem model consists of the ammonia feed pump, the ammonia valve, the bypass valve, the recirculation valve, and the recirculation bypass valve, as shown in Figure 3-138. The figure shows the cycle with the inlet and exit of every major component numbered. These numbers are used to clearly and concisely refer to locations in the OTEC cycle. Table 3-47 shows each of the instrument locations, with the numbered position corresponding to the numbers in Figure 3-138.

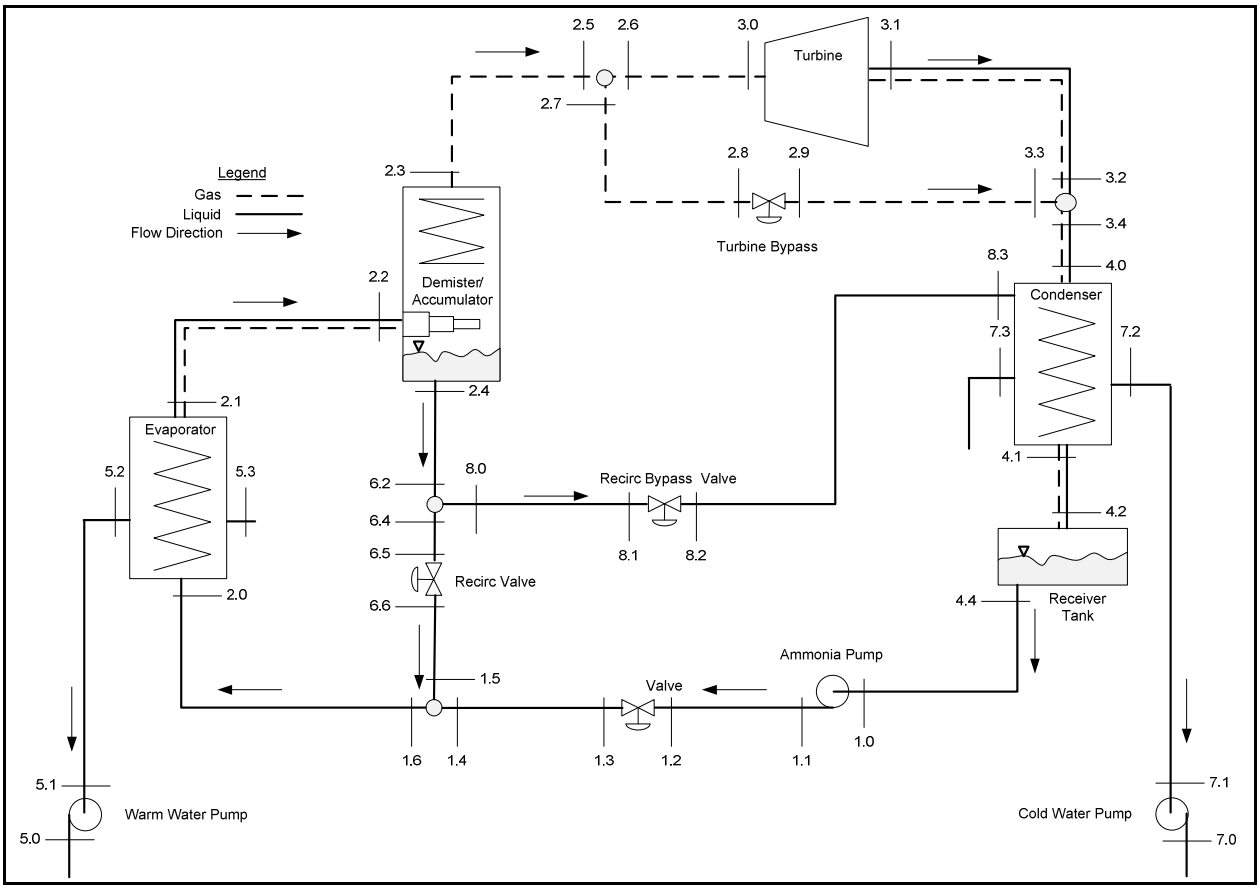


Figure 3-138. Power Cycle Includes Turbine and Recirculation Bypass Loops

Table 3-47. Working Fluid Subsystem Instrumentation

Sensor Type	Location	Rationale	Redundant
Temperature	1.1	Performance Calculations	Yes
Pressure	1.0	Pump Control/Alerts	Yes
Pressure	1.1	Performance Calculations	No
Delta Pressure	1.0-1.1	Alerts	Yes
Flow	1.3-1.4	Pump and Valve Control, Alerts	Yes
Temperature	2.0	Performance Calculations	Yes, one at the inlet to each unit
Pressure	2.0	Performance Calculations, Pump and Valve Controls	Yes, one at the inlet to each unit
Temperature	2.1	Performance Calculations	Yes, one at the outlet to each unit
Pressure	2.1	Performance Calculations	Yes, one at the outlet to each unit

Sensor Type	Location	Rationale	Redundant
Temperature	2.3	Performance Calculations	No
Pressure	2.3	Performance Calculations	No
Liquid Level	Demister	Recirculation and Recirculation Bypass Valve, Ammonia Mass Bookkeeping	Yes
Flow	2.6-3.0	Turbine Bypass Valve, Governor	Yes
Temperature	3.0	Governor, Performance Calculations	Yes
Pressure	3.0	Governor, Performance Calculations	Yes
Temperature	3.1	Governor, Performance Calculations	Yes
Pressure	3.1	Governor, Performance Calculations	Yes
Delta Pressure	3.0-3.1	Governor, Performance Calculations	Yes
Flow	2.9-3.3	Performance Calculations, Turbine Bypass Valve	Yes
Temperature	4.0	Performance Calculations	Yes, one at the inlet to each unit
Pressure	4.0	Performance Calculations, Pump and Valve Controls	Yes, one at the inlet to each unit
Temperature	4.1	Performance Calculations	Yes, one at the outlet to each unit
Pressure	4.1	Performance Calculations	Yes, one at the outlet to each unit
Liquid Level	Receiver Tank	Pump Control, Ammonia Mass Bookkeeping	Yes
Temperature	4.2	Performance Calculations	Yes, one at the outlet to each unit
Pressure	4.2	Performance Calculations	Yes, one at the outlet to each unit

A controls analysis was performed that drove requirements for this subsystem along with the warm and cold water subsystems. The results are discussed in sections 3.3.4.2 and 3.3.4.2.1.

3.3.2.1.3 Warm Water Subsystem

The warm water subsystem is comprised of the warm water intake screen, chlorination system, evaporators, seawater ducting, seawater pump and discharge diffuser. These components are illustrated in Figure 3-139. Table 3-48 lists some of the key decisions for the warm water subsystem.

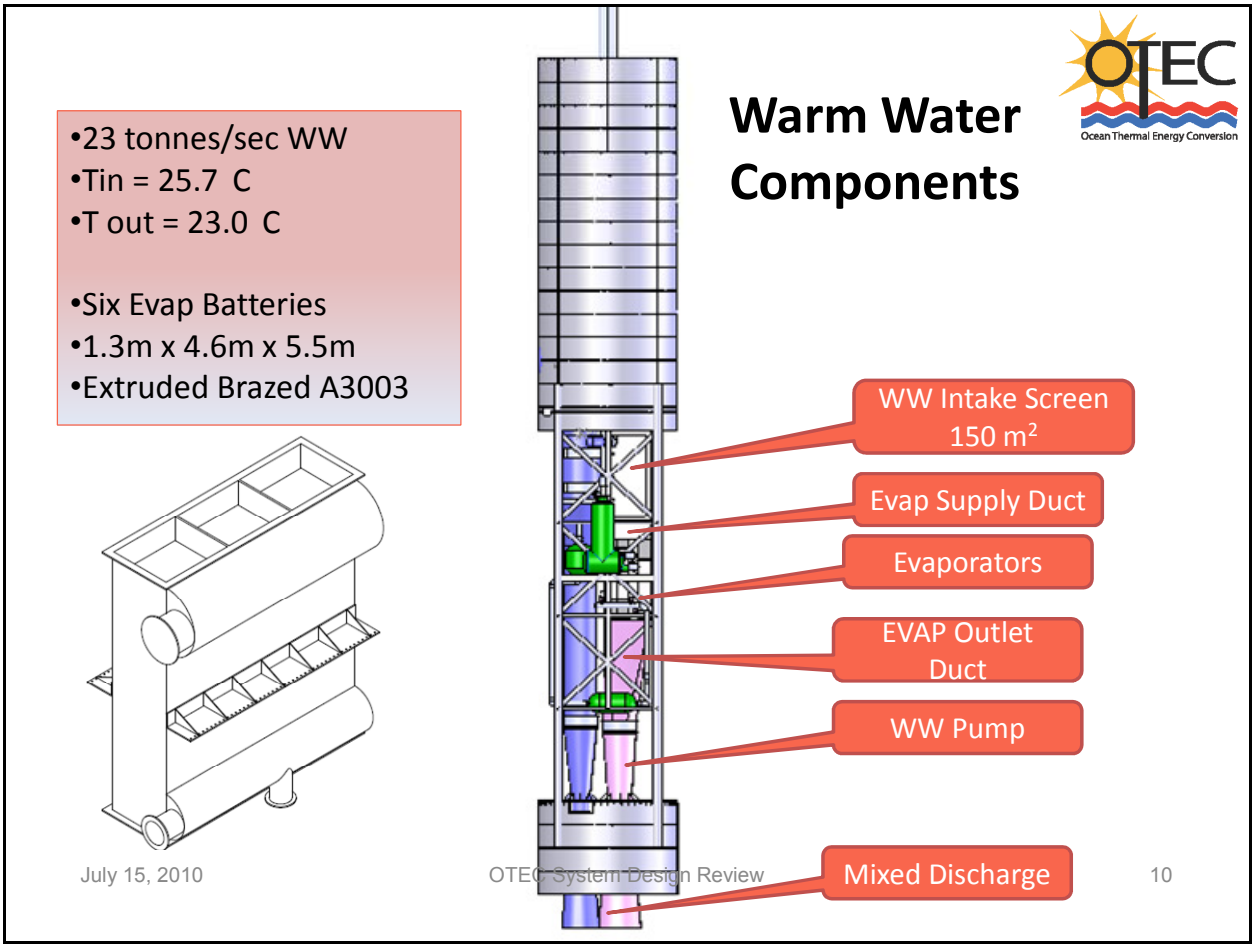


Figure 3-139. Major components and parameters of warm water system

Table 3-48. Key considerations for Warm Seawater system

Trades / Decisions	Results and Rationale
WW Intake Screen Impingement / Entrainment	Velocity < 0.15 m/sec. Mesh size = 8mm. 20-30m deep.
Single WW Pump	Most economical & efficient WW ducts. Sacrifices quick shift to redundant pump.
Submerged WW Pump	Best inlet geometry. Adequate NPSH despite heaving in storms.
Discharge depth 70m (only)	70 m seems adequate per Makai CEROS plume model to prevent reingestion and high nitrogen levels.
Discharge Speed 1.2 m/sec	Saves pumping power. ½ m *d*V2

3.3.2.1.3.1 Evaporator Heat Exchanger

Background

At commercial scale (~100 MW); evaporator costs represent a significant portion of the total cost of an OTEC plant (~15%). Therefore, evaporator development represents an opportunity for reduction in total plant cost. In recognition of this opportunity, the pilot plant design effort included heat exchanger development despite the fact that evaporators only account for a small percentage of pilot plant total cost (~5%).

The first step in evaporator development was selection of a heat exchanger concept for development. Research conducted by Makai Ocean Engineering as part of a Phase II Small Business Innovation Research (SBIR) in 2007 identified brazed-fin aluminum heat exchangers (hereafter brazed heat exchanger) as good candidates for OTEC evaporators.

Brazed heat exchangers offer high performance and a compact form factor, which makes them attractive for OTEC applications. They have been considered for OTEC applications since 1981, when a Trane-built unit was tested at Argonne National Labs. Based on the prior research, brazed heat exchangers were selected for use in the pilot plant.

Brazed Heat Exchanger Overview

A brazed heat exchanger is constructed of alternating layers of fluid passages. The layers are formed from large plates called parting sheets; the parting sheets are separated by fins that enhance heat transfer and improve efficiency. A diagram of a brazed heat exchanger is shown in Figure 3-140.

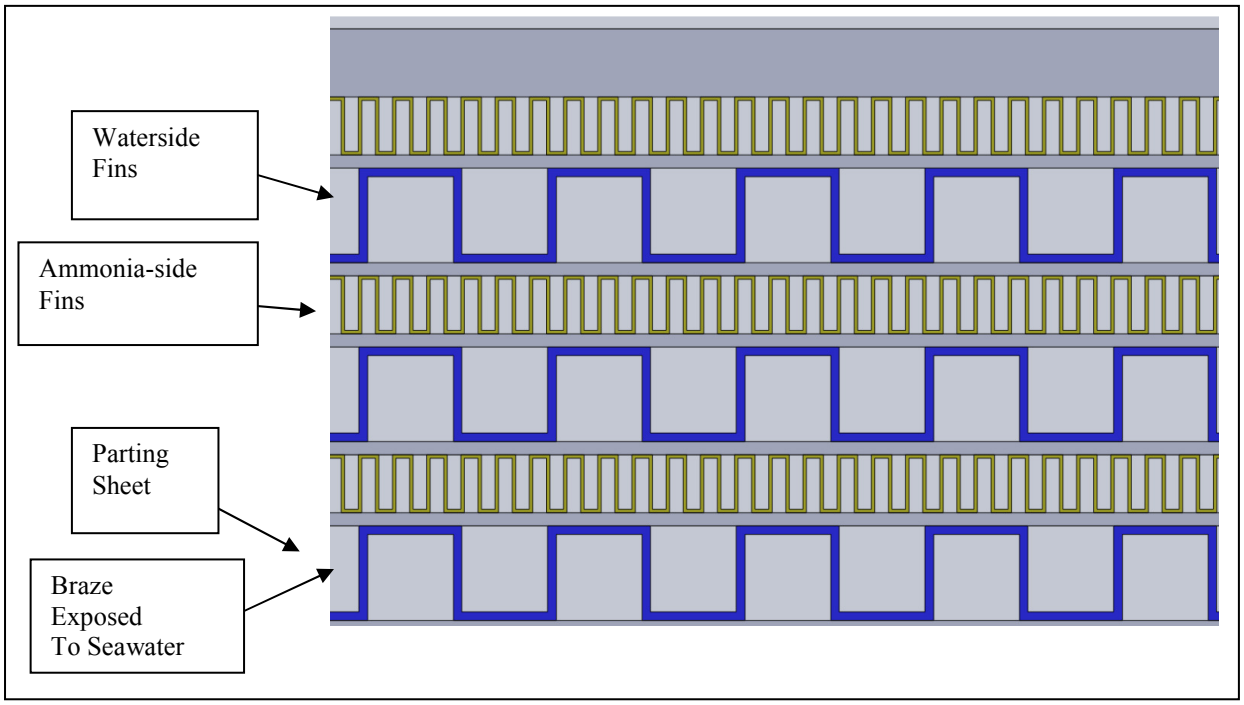


Figure 3-140. Brazed Heat Exchanger Structure

In one layer flows seawater, and in the other flows the working fluid (ammonia). Heat is transferred from the warm seawater to the slightly cooler ammonia. The ammonia pressure is selected such that it will begin to boil as it absorbs energy from the seawater. The ammonia vapor that is produced is collected at the top of the heat exchanger and directed to the turbine and work is extracted.

The heat exchanger is constructed by stacking parting sheets and fins along with thin rods of braze metal. The braze metal melts at a slightly lower temperature than the parting sheets and fins (made of a "base metal"). The stacked structure is then clamped tightly and placed in a brazing oven. The oven heats the structure to the melting point of the braze metal (but not quite to the melting point of the parting sheets and fins). The braze metal melts and flows into the gaps between the parting sheets and fins by capillary action. When the heat exchanger cools, the braze metal bonds the rest of the structure together.

Corrosion

The challenge with using brazed structures in seawater applications is that the braze metal is necessarily different from the base metal. The dissimilar metals will set up a galvanic cell when immersed in seawater and cause corrosion. One solution to this problem is to isolate the braze metal from the seawater environment. Dissimilar metals immersed in ammonia will not be subject to galvanic corrosion. The method of isolation selected for the pilot plant is the use of extruded waterside channels. These extruded channels replace the parting sheet/fin structure that would be used for a typical brazed heat exchanger. A diagram of brazed fin heat exchanger structure using extruded channels is shown in Figure 3-141.

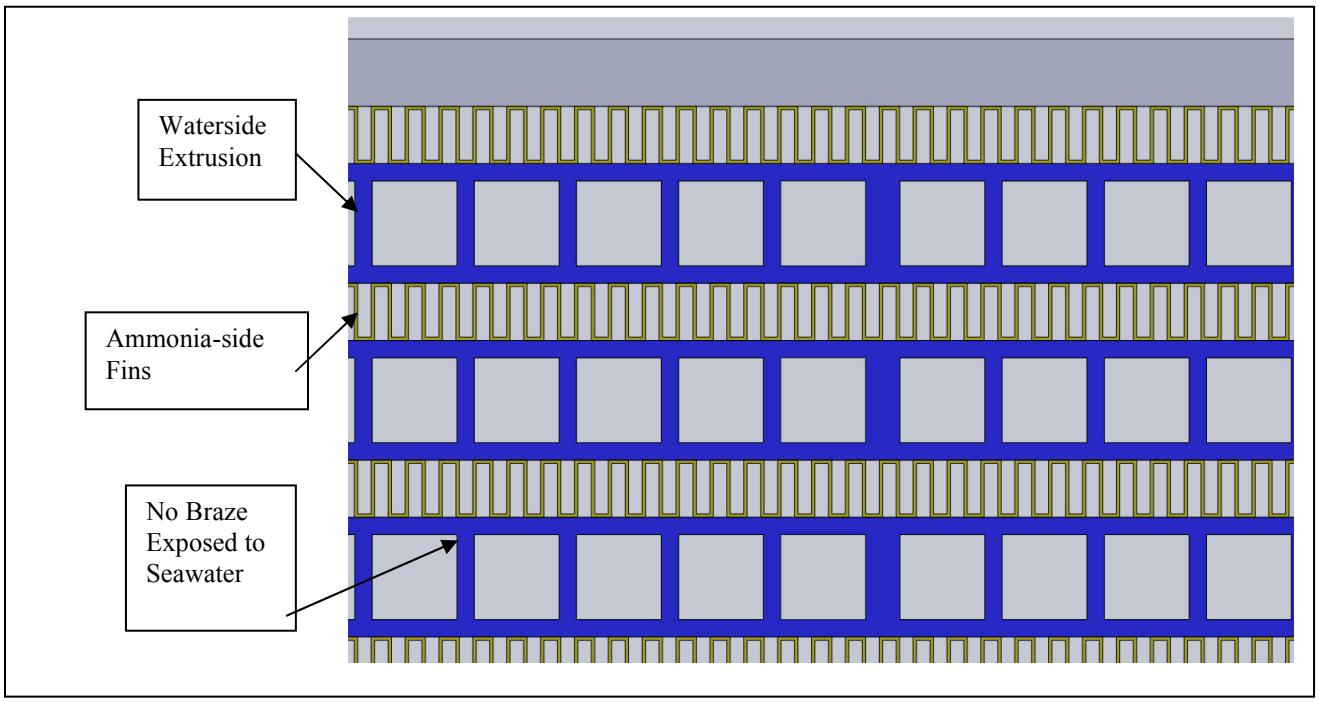


Figure 3-141. Brazed Heat Exchanger Structure with Extruded Waterside Channels

Note that no parting sheets are used - each extruded channel replaces two parting sheets and the fins that would separate them. Brazing occurs between the ammonia-side fins and the outside of the extruded channels. Since the extruded channels completely enclose the seawater, no braze metal is exposed and galvanic corrosion is eliminated.

Although use of extruded passages eliminates galvanic corrosion concerns, pitting corrosion is also a factor. A pit is an area of local corrosion that becomes isolated from the environment and can penetrate deeply into the material. Aluminum naturally forms a protective oxide layer that prevents pitting corrosion. However, this layer can be disrupted and pitting can begin if the layer is not reestablished quickly enough. Reestablishment of the protective layer is a function of the oxygen content of the water.

Since the evaporators will be used in well-oxygenated surface seawater, pitting corrosion is not expected to be a problem. Existing literature on aluminum corrosion in seawater supports this conclusion and further research is currently underway at the Natural Energy Lab of Hawaii Authority. More research results are expected before final design of a pilot plant would be completed.

Design Optimization

Once the extruded channel concept had been selected, it became necessary to identify what heat exchanger parameters would best suit OTEC. The primary variable in the design process is the nature of the fins. Note that the webs of the extruded channels are analogous to fins from a heat transfer standpoint and the term "fins" in the following discussion applies to "webs" as well. Fin height determines the space between the parting sheets (or the height of the extrusion). This has a significant impact on water flow area and therefore fluid velocity and head loss. Short fins yield high fluid velocities. High fluid velocities yield high heat transfer rates but also high head losses. High heat transfer is desirable because it minimizes overall heat exchanger size, but high head loss is undesirable because it increases the amount of OTEC-generated electricity required to run pumps and decreases the amount that can be sold. Additionally, short fins reduce overall heat exchanger size and cost. Similarly, fin density (the number of fins per meter along a parting sheet or extrusion) impacts both heat transfer and head loss. High fin densities enhance heat transfer, but also increase head losses.

A heat exchanger optimization process focused on selection of fin heights and fin densities was carried out in fulfillment of a different contract conducted in parallel with the pilot plant effort. This process utilized a commercial heat exchanger program, ProSec, to model a variety of potential configurations. Technical support from Chart Industries Inc., a brazed heat exchanger manufacturer, supplemented ProSec results with respect to ammonia-side fin design. The suitability of each configuration was evaluated using a heat exchanger scoring rubric based on MOTEM - Makai Ocean Engineering's Thermo-Economic OTEC Model. The rubric assigned a high score to heat exchanger designs that favored a low overall OTEC plant cost.

The highest scoring heat exchanger design from the optimization process was selected for use in the pilot plant. It was also selected as first evaporator to be tested at the heat exchanger test facility currently under construction at the Natural Energy Lab of Hawaii Authority. The technical details of the optimization process are proprietary and are outside the scope of this report. However, the heat exchanger overall dimensions, weight, and performance are not proprietary, and these values were used for the pilot plant design. Figure 3-142 shows the overall dimension of the heat exchanger core resulting from the optimization process, and Figure 3-143 shows its performance characteristics.

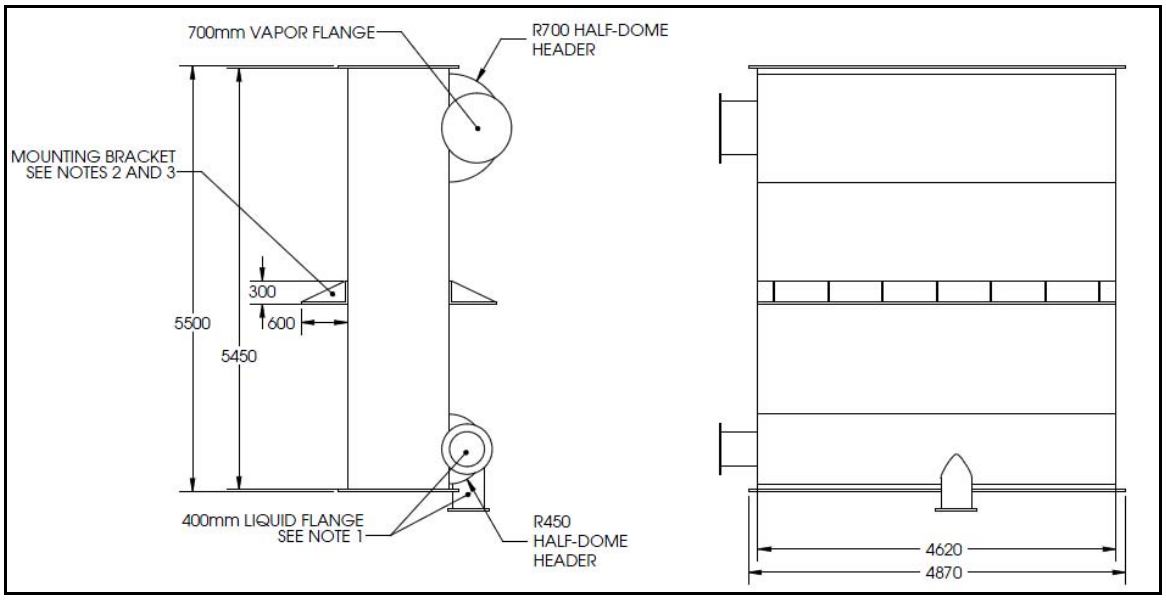


Figure 3-142. Overall Dimensions of Brazed Heat Exchanger Core Used for Pilot Plant Design (all dimensions in mm)

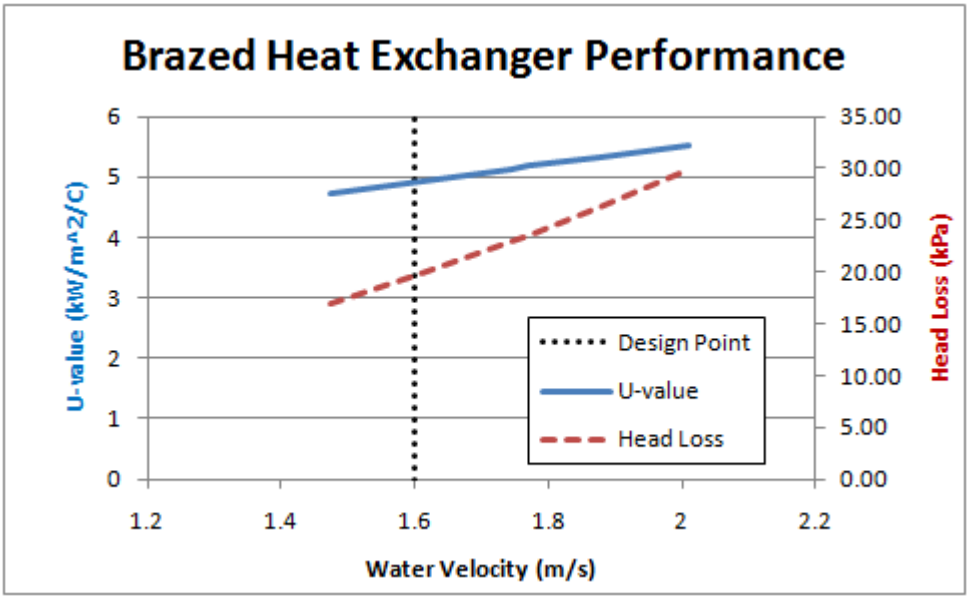


Figure 3-143. Evaporator Performance

The nominal operating conditions for the heat exchanger are 1.6 m/s water velocity, an overall heat transfer coefficient of 4.9 kW/m^2/^{o}C, and waterside pressure drop of 20 kPa.

Mounting and Manifolds

With the core design established, evaporator design progressed to mounting systems and ammonia manifolds. The heat exchangers must be mounted securely to the truss structure that makes up the remora. Preliminary load analysis was carried out to estimate the maximum load that will be imposed on the mounting system. Note that final determination of expected loads requires complete characterization of the remora and platform and is therefore delegated to final design of the pilot plant.

The maximum expected load during the 2 year pilot program is approximately 60 kN. This is the load associated with a violent storm; max wave height = 10 m, wave period = 10 s, and current = 0.7 m/s. This condition is more severe than any expected long-period swell loads and serves as the design condition for the first two years. In the case of the 20 year afterlife, the mounting system must survive the 100-year hurricane - a load of 135 kN. Since it has not been definitively decided that the remora will be refit between the pilot program and the afterlife, 135 kN was conservatively used as the design load for the mounting system.

Brazed heat exchangers typically supported with angle irons that are welded to the side of the unit and bolted to a foundation. This arrangement was deemed suitable for installation in a remora with the added protection of galvanic isolation. The heat exchanger will be constructed of aluminum while the foundation will be made of the steel. If the two metals were in direct contact, galvanic corrosion would ensue. Electrical isolation will be accomplished via commercially available bearing pads (e.g. - Micarta) and shoulder washers.

Ammonia manifolds could potentially be a high-cost component of an OTEC plant. Connection of manifold piping is labor-intensive, and the large heat transfer areas required by OTEC necessitate many individual heat exchangers - each of which must be plumbed into a single system. The limiting factor on the number of heat exchangers that must be connected is the maximum size of each unit. The maximum size is affected by manufacturer capabilities, shipping logistics, and practicality of installation into a remora. The problem has been mitigated for the pilot plant by grouping heat exchangers into groups of 3.

An individual brazed heat exchanger is known as a “core,” and is 1.3 m wide by 1.5 m deep by 5.5 m tall. A core includes the extruded waterside passages, the finned ammonia-side passages, and outside plates that separate the passages from the outside environment. A core does not include the ammonia piping that directs liquid into, and vapor out of, the heat exchanger. The location where the ammonia manifolds will be attached is left open so they can be welded after brazing. Normally, each core would get its own manifold and would therefore have its own flange to be connected to the remora ammonia ducting system. However, the modular nature of the cores allows them to be welded together before manifolds are attached. The pilot plant heat exchanger concept uses groups of 3 cores welded together. Once the cores are welded, a single manifold that spans all three cores is attached. This reduced the number of required ammonia connections by a factor of 3. Both vapor and liquid manifolds take advantage of this configuration. Figure 3-144 shows the 3-core configuration and multi-core manifolds.

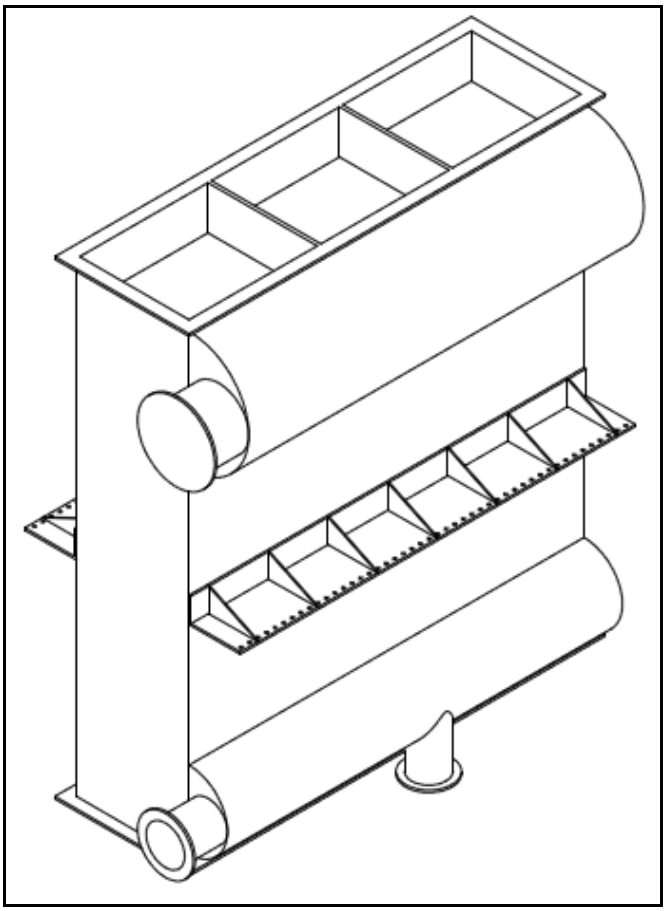


Figure 3-144. Core Heat Exchanger Concept

The above concept requires 6 vapor connections and 6 liquid connections to be made during heat exchanger installation per remora. The vapor connections go to one of two demisters that remove liquid ammonia droplets from the vapor stream. The liquid connections come from the ammonia pump pods.

3.3.2.1.3.2 Warm Water Ducting

The primary parasitic loads on the OTEC plant come from the seawater pumps. The amount of power required to run the pumps is driven by the hydraulic losses through the flow path. Warm water hydraulic losses are dominated by those imposed by the evaporators and the remora ducting. Evaporator head losses are covered in section 0. Analysis of remora ducting losses is discussed below.

Head losses were determined using the same methods employed for more conventional ducting systems. The average flow velocity was first calculated for each component of the flow path: warm water screen, heat exchanger inlet, heat exchanger outlet, pump inlet nozzle, discharge diffuser, and discharge outlet. Each component was then assigned a loss coefficient (k-value). The heat exchanger inlet, heat exchanger outlet, pump inlet nozzle, and discharge diffuser

include acceleration or deceleration of the flow, and calculation of the loss coefficient for these components was done according to:

$$K = 0.8 \sin\left(\frac{\theta}{2}\right)\left(1 - \frac{{d_1}^2}{{d_2}^2}\right)$$

and

$$K = 2.6 \sin\left(\frac{\theta}{2}\right)\left(1 - \frac{{d_1}^2}{{d_2}^2}\right)^2$$

Where θ is the angle of contraction or expansion, and *d* is the diameter of the duct.

A conservative loss coefficient of 0.5 was assumed for the warm water screen, and the discharge outlet was assigned a loss coefficient of 1. The head loss for each component was then calculated according from the flow velocity and loss coefficient according to:

$$H = \frac{K v^2}{2g}$$

Where *H* is the head loss, *K* is the loss coefficient, *v* is the flow velocity, and *g* is the acceleration of gravity.

A summary of the results of the analysis is shown in Table 3-49.

Table 3-49. Summary of Remora Warm Water Hydraulic Losses

Component	Flow Velocity [m/s]	Loss Coefficient	Head Loss [m]
Warm Water Screen	0.21	0.50	0.001
Heat Exchanger Inlet	0.95	0.28	0.013
Heat Exchanger Outlet	0.95	0.25	0.011
Pump Inlet Nozzle	3.05	0.20	0.096
Discharge Diffuser	3.05	0.17	0.082
Discharge Outlet	0.05	1.00	0.051
Total Head Loss			**0.254**

Warm Water Ducting Components

As shown in Figure 3-145, the warm water system is comprised of the following components:

- Warm water penstock
- 6 x Evaporators
- Converger
- Seawater pump
- Diffuser

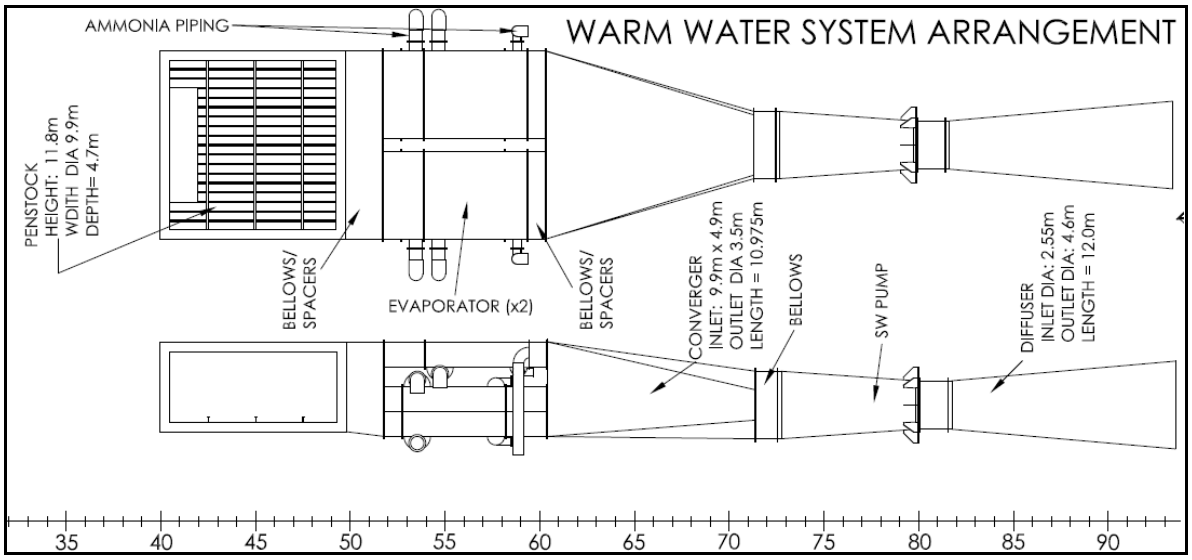


Figure 3-145. Arrangement of Warm Water Ducting

The evaporators and seawater pump are isolated from the structure by flexible spacers capable of withstanding external pressure. These spacers consist of two basic sets, since the two evaporators are located at different heights.

The penstock is a steel warm water holding tank that has been designed to ensure that warm water enters the system horizontally, as opposed to vertically, in order to minimize the disruption to fish. All of the penstock openings are covered with screen discussed elsewhere in this report. The penstock structure has been designed using the same ABS FPI Rules as used for the rest of the remora structure.

The converger collects the outflow of water from the two evaporators and funnels the water into the warm water pump. The converger is constructed of stiffened steel plate. The plate stiffening is located on the external face of the plates and is not shown in the above drawing.

The diffuser was designed for clean flow through the diffuser in order to minimize losses in power generation. The size of the diffuser was designed using Blevins, Figure 3-147. The intent was to design a diffuser whose performance was well within the “no appreciable stall” area on this figure. The calculations are included in Appendix 3.3-33.

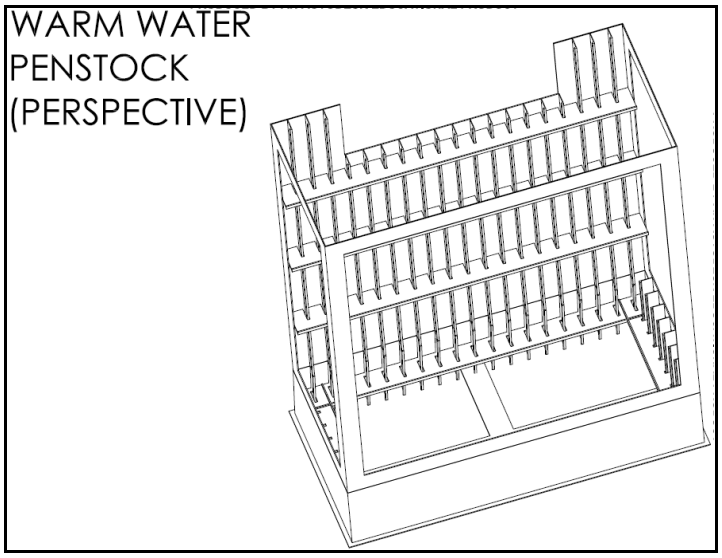


Figure 3-146. Perspective of Warm Water Penstock

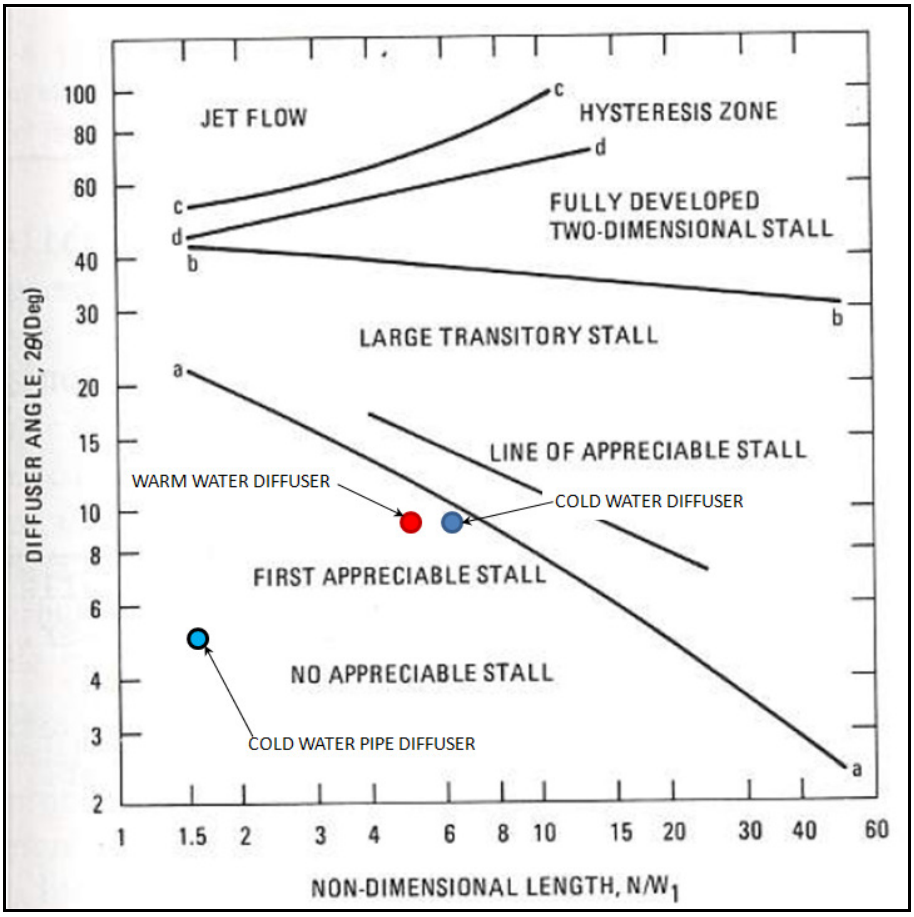


Figure 3-147. Cold and Warm Water Diffuser Performance

3.3.2.1.3.3 Warm Water Pumps

Over the past two years, Lockheed Martin (LM) has devoted significant resources including Independent Research and Development (IR&D) funds to the investigation, research and selection of Sea Water Pumps for the Ocean Thermal Energy Conversion (OTEC) application. That effort has yielded a wealth of information regarding pumps produced for the Water and Waste Water industry. In an effort to reduce the amount of rotating equipment in the system, reduce losses associated with pipe friction, and allow a simplified and hydraulically efficient design, we have decided to pursue very large axial flow pumps. Manufacturers with the capability of producing such large axial pumps are rare. Pumps which meet our criteria can be divided into two basic categories: Submersible Motor and Dry Motor Axial Pumps. Few manufacturers have the capability to produce both varieties.

Submersible vs. Dry Motor Pumps

In recent years, submersible pumps have begun to replace traditional dry motor long-shaft pump designs in water and waste water applications. Submersible pumps incorporate the motor, shaft, and hydraulics into one fully submersible unit (see Figure 3-149). Dry motor configurations typically consist of independently supported dry motors, longer shafts, and submerged hydraulics (see Figure 3-149). As with most hydraulic technologies, development of submersible pumps originated in Europe and has only recently spread to the Americas.

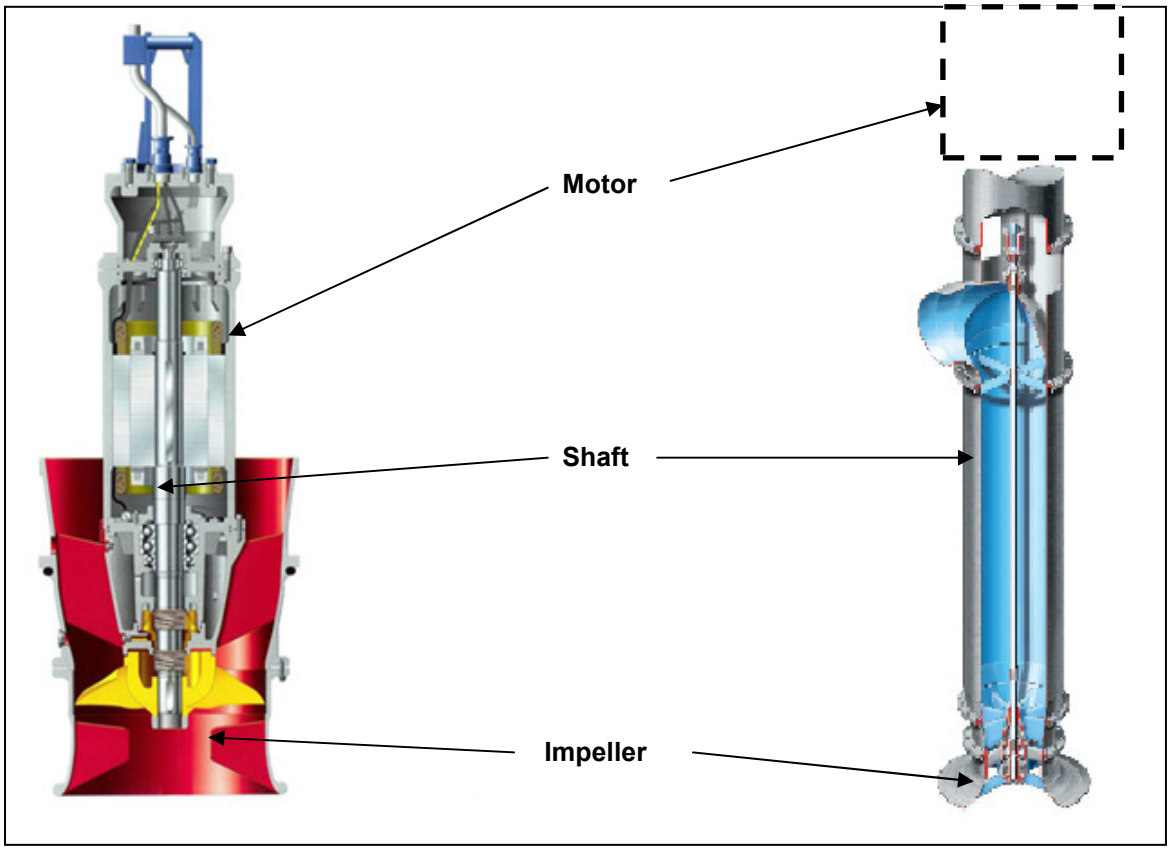


Figure 3-149. Submersible motor pump (Left) and dry motor pump (Right)

Submersible pumps are regarded by many in the water and waste water industry as the way of the future. While there are advantages and disadvantages associated with each design, our team has decided to mitigate multiple risks through incorporation of submersible pumps in the design of the NAVFAC Pilot Plant. The team used the following discriminators in selecting submersible pumps as the best option:

Hydraulic Layout - Dry motor configurations inherently complicate hydraulic layout with inclusion of the dry compartment for motor placement and independent mounting for the motor, shaft, and hydraulics. Submersible pumps allow simpler placement with a single mounting point at the mid-section and compact construction. Submersible pumps can be designed for any vertical or horizontal orientation with only minor changes to bearing design. Furthermore, their static and mechanical seals are typically designed for submergence up to 60 meters with no effect to operation.

Warranty - The compact construction of a submersible pump requires that parts be match machined to fit directly together as one assembly and tested as such. This dependency forces manufacturers to either wind their own motors for pump construction or source motors directly and install them under their own warranty. In contrast, dry motor pumps typically consist of hydraulic components built by the pump manufacturer and a motor sourced from a standard motor manufacturer. When problems arise in operation of the unit, the motor manufacturer might be accused by the pump manufacturer and vice versa. In addition, several unknowns are present with regard to mounting and bearing design for each dry motor installation. With greater possibility of shaft resonance, bearing wear, and misalignment, there is a higher possibility of premature failure in a dry motor design.

Efficiency - Efficient operation of any OTEC Plant is directly coupled to efficient operation of its Sea Water Pumps. Sea Water Pump power consumption accounts for roughly 20% of Gross Plant Power. A 3% increase in Sea Water Pump efficiency allows for roughly 1% increase in Net Plant Power.

Most submersible pumps are oil-filled devices allowing internal case pressures to equalize with external static pressure. This design feature lessens the possibility of leaks. Oil-filled motors will also reject heat better from high wear devices such as seals and bearings, usually leading to longer life of the pump. However, oil-filled motors are inherently less efficient than air filled and water jacketed motors due to viscous losses of the moving components. This efficiency difference equates to roughly 5% in favor of the dry motor design. However, LM has identified a submersible pump manufacturer with an air-filled motor design. In this situation, there is no efficiency difference between submersible and dry motor solutions.

Access - The motor in a Dry Motor configuration is potentially more accessible (akin to an engine room) than in a submersible configuration. If the space is designed for convenient human access, typical maintenance tasks such as oil changes and sensor calibration become simpler because they will not require divers. However, the hydraulic path for a dry motor configuration is likely to be more complicated than with a submersible configuration. The dry motor configuration also requires a mechanical seal in the dry compartment where the shaft intercepts the motor. Maintenance on this seal may require removal of the motor (including accessories) and complex maintenance procedures to prevent flooding of the dry compartment. While

removing a submersible pump for maintenance will involve divers working at depths exceeding 60 meters, the entire pump system can be assembled and realigned prior to being re-inserted.

Accessories - A submersible pump is a single complete pumping solution, often with a single cable to carry power to the unit and health monitoring signals to the platform. The motor is cooled by passing water and oil is circulated by mechanical drive. However, most commercial style motors, as used in the dry motor configuration, require separate systems for cooling and oil circulation. This introduces additional points of failure, products from various manufacturers and additional maintenance items.

Flow Pulsations - The discharge flow of pumps carries with it vibrations that can do serious damage if the frequency and amplitude are able to excite structures downstream. In the dry motor configuration, the pump would be sited upstream of the heat exchanger. This would leave the heat exchanger susceptible to pressure pulsations produced by the pump impeller. The seriousness of this concern will depend on heat exchanger design and materials, as well as impeller design details. Without the incentive of placing a firm order, pump manufacturers were unable to quantify this pulsation effect. This uncertainty was mitigated by using submersible pumps located downstream of the heat exchangers.

Pump Particulates and Heat Exchanger Corrosion - Operation of any mechanical system will produce wear on bearing surfaces and mechanical seals, causing eroded particles to be carried downstream. If the heat exchanger is downstream of the pump hydraulics, as in the dry motor design, these eroded particles may be trapped on the heat exchanger surface. These particles would be of dissimilar electrolytic potential and could become initiation sites for localized pitting corrosion on the heat exchangers. This was a major factor in deciding to pursue the submersible pump option for the Pilot Plant design.

Pump Submergence to Prevent Heave-Induced Cavitation. During significant wave events such as large swell, the platform and the one-kilometer-long cold water pipe may heave up to several meters, causing pressure fluctuations at the impeller inlet. If the pump impeller was placed relatively near the surface, these heave-induced fluctuations could create momentary cavitation. Such an effect was reported by OTEC-1 at the cold water pump. (Note, the pilot platform would heave less than the ship-shaped OTEC-1.) By using submersible pumps at 60 meters submergence, adequate net positive suction head is available so that the impellers would not cavitate during these fluctuations. The primary effect of platform heave would be a pulsating flow caused by variation of total dynamic head.

Installation/Removal

Typically, submersible pumps are mounted vertically on land in an open-ended tube. In this case, installation/removal is a one-step process with a direct vertical hoist as seen in Figure 3-151. But if the pumps are to be transported to shore, the pumps must be placed onto a barge, which is subject to heave motions. This means that the hoisting crane should be heave compensated to match the barge's heave motions. In addition, the remora's buoyancy tanks and heat exchangers are located above the seawater pumps. No direct vertical path exists for access to our Sea Water Pumps. This leaves us with three options:

1. Enlarge for Direct Vertical Access. Expand the volume of the Remora to accommodate direct vertical access for pump installation and removal. This option increases the footprint of the Remora affecting its construction, transport and cost negatively. It also requires a rather tall barge-mounted crane.
2. Vertical Lowering. This option requires that the pump be lowered from within the duct through a slightly oversized discharge duct, and then transferred to an external hoist at depths exceeding 70 meters. This option requires diving inside the seawater ducts at depths of approx 60 meters deep, with additional diving needed at approx 80 meters deep to connect the external hoist cable. Two hoisting systems would be needed.
3. Slide Out. This option resembles the operation of a desk drawer. The remora structure is exposed around the vertical location of the pumps. The semi-permanent fasteners (bolts) are removed between the pump and connecting ducts. The pump is then slid to the side of the Remora using a truss structure for vertical support and a winch system for movement. At this point, the pump is hoisted vertically out of position and onto the platform for service. Slide out requires diving at depths of approx 60 meters deep, while remaining outside of the seawater ducts. Only one hoisting system (from the transport barge) is needed. Installation is reverse of removal.

The team selected the Slide Out option - depicted in Figure 3-150. It is the simplest hoisting procedure and involves the shallowest diver work.

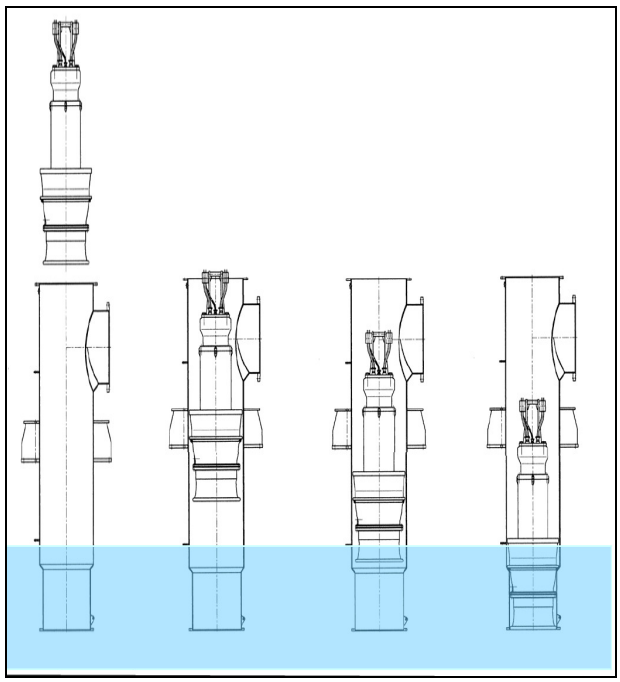


Figure 3-150. Typical Submersible Installation

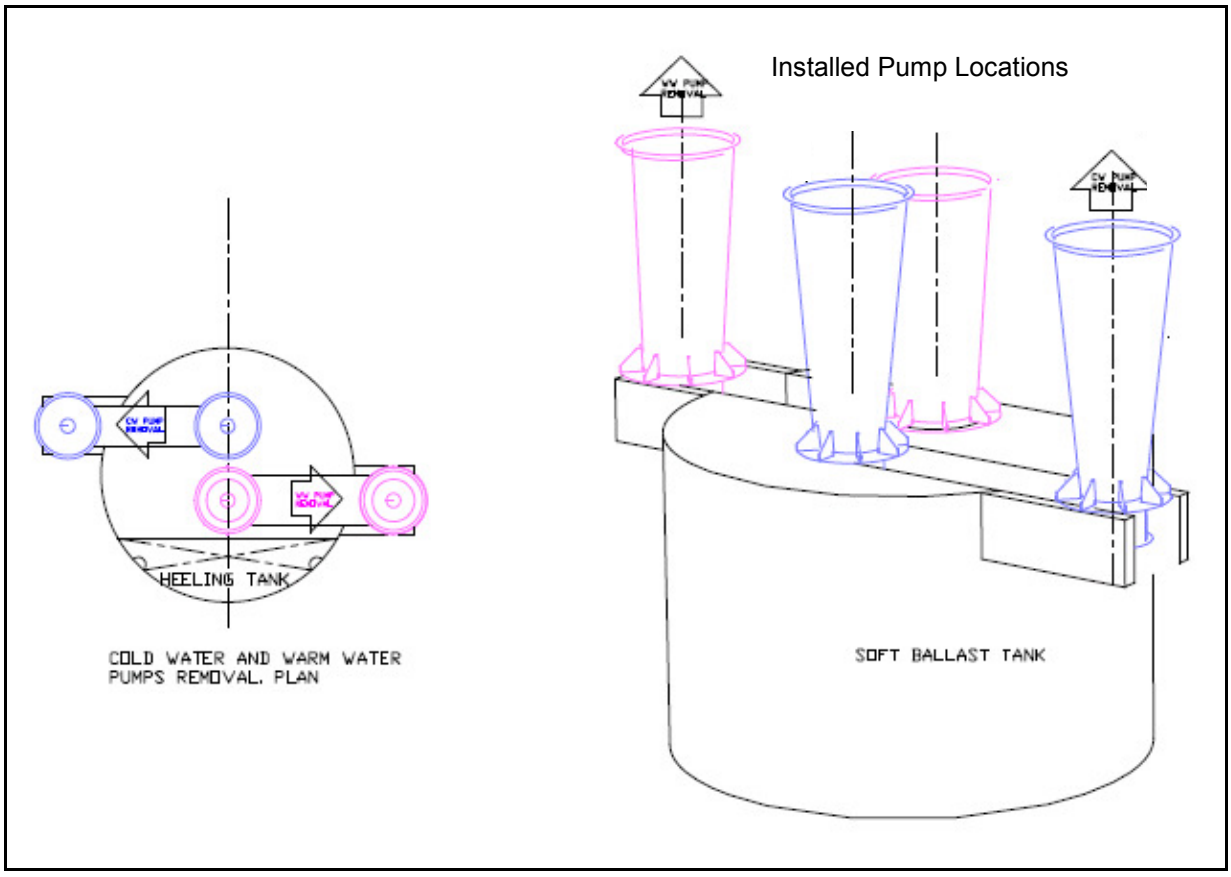


Figure 3-151. Option 3 - Slide-Out Installation/Removal Concept

Warm Water Pump Design Conditions

Design Point: 22.4m³/s @ 2.5m Total Dynamic Head

Density of Water: 1027kg/m³

Temperature: 23.0˚C

The Warm Water Pump Design point shown above was established by pressure drop across the heat exchangers and other dynamic losses determined by MOTEM. These losses were established at the reference water temperature and density given above.

Several pump manufacturers provided the design team with seawater pump dimensions, size, weight and performance data, with budgetary cost estimates. This information is considered to be both LM Proprietary and 3rd Party Proprietary Information and is not included within this report. It can be made available to NAVFAC upon request.

3.3.2.1.3.4 Warm Water Corrosion Control

The pre-FEED design for the evaporator is comprised of a battery of six extruded, brazed aluminum alloy 3004 compact type heat exchanger elements. The evaporator is designed such that the brazing material is exposed only to the ammonia side of the evaporator. Only aluminum alloy 3004 is exposed to the seawater, thus eliminating galvanic corrosion concerns between the aluminum and brazing material. Each evaporator element is 1.3m x 4.6m x 5.5m**.** Inlet water temperature is 25.7°C and outlet temperature is 23.0°C.

During this pre-FEED phase the long term corrosion resistance of a full scale or model evaporator has not yet been validated, however the principal corrosion issues can be defined and specific mitigations implemented in the FEED.

The primary challenge for corrosion management in these warm surface water temperatures is (a) pitting corrosion of the aluminum components of the exchanger (b) galvanic corrosion of the aluminum heat exchangers, and (c) crevice corrosion at the connecting components.

Pitting corrosion is of particular importance since, once it has perforated the heat exchanger wall the exchanger element would need to be replaced as it cannot be repaired with the current evaporator configuration.

External corrosion of the evaporator can also be aggravated by galvanic corrosion between the evaporator and the steel hull supporting structure. This will be partially mitigated if the remora hull components are cathodically protected as the protection of the steel will bring the galvanic potential of the steel supporting structure closer to that of the aluminum. However, in order to insure that the corrosion of the exterior of the aluminum evaporator is not increased by galvanic effects, it is recommended that a dielectric shield be installed around the evaporator to minimize any remaining galvanic effects.

Because crevice corrosion of the evaporator mounting is a concern, the detailed design of the structural mountings will take into account the specific OTEC warm water environment which induces significant amounts of crevice corrosion. Other non-structural connections to the evaporator will also have to be designed to accept significant crevice corrosion.

3.3.2.1.3.5 Warm Water Biofouling Protection

Current plans are to mitigate the effects of biofouling in the evaporator by the injection of chlorine into the warm water supply. The level of chlorination required has not been fully validated, but intermittent chlorination in the range of 100 to 150 parts per billion is currently envisioned. Even at these low levels of chlorination, the amount of chlorine being used is significant. If generated by electrolysis on site, the power requirements for chlorine generation must be considered in the overall cycle efficiency. If chlorine is transported to the site, cost of material, transportation and on-site storage must be considered and will be defined in the FEED phase of this design.

The environmental effects of chlorination will depend on the final level of dosing required and the details of this method will be reviewed and addressed with environmental regulators as part of the FEED design.

3.3.2.1.3.6 Warm Water Instrument and Control

The instrumentation for the warm water subsystem consists of temperature, pressure, and flow sensors. The controls for the warm water subsystem consist of the warm water pump, and the chlorination system. The chlorination system is described in section 3.3.2.1.3.5. Table 3-50 shows each of the instrument locations, with the numbered position corresponding to the numbers in Figure 3-138.

Table 3-50. Warm Water Subsystem Instrumentation

Sensor Type	Location	Rationale	Redundant
Temperature	5.3	Performance Calculations	Yes, one at the inlet to each unit
Pressure	5.3	Performance Calculations	Yes, one at the inlet to each unit
Temperature	5.2	Performance Calculations	Yes, one at the outlet to each unit
Pressure	5.2	Performance Calculations	Yes, one at the outlet to each unit
Flow	5.2-5.1	Performance Calculations	Yes
Delta Pressure	5.3-5.2	Alerts	Yes
Delta Pressure	5.1-Exit	Alert	Yes
Delta Pressure	5.3-Outside	Alert	Yes
Inlet Camera	Outside	Visual For Screen Blockage	No
Ammonia Sensor	5.1	Alert	No
Chlorine Sensor	5.1	Alert	No

A controls analysis was performed that drove requirements for this subsystem along with the working fluid and cold water subsystems. The results are discussed in sections 3.3.4.2 and 3.3.4.2.1.

3.3.2.1.4 Cold Water Subsystem

Key considerations for the cold seawater system are listed in Table 3-51. These items are discussed later in this section, except that the first item is an important issue that has not yet been finalized.

Table 3-51. Key considerations for Cold Seawater system

Trades / Decisions	Results and Rationale
No CW Intake Screen	Experience at Kona suggests no screen is required Inaccessible at 1 km depth Important criteria for permitting Consider bellmouth precedent
Single & submerged CW pump	NPSHa more important for CW Similar layout as WW pump
Crossover duct & elbow sizing compromise	CFE. Large duct better flow, but small duct less wave loading
Discharge depth & discharge speed	Avoid nitrogen in photic zone Power ½ mdV^2, cost Plume model shows 70m at 1 m/s adequate NOAA & EPA: TBD
Strainer	Prevent large organisms clogging condenser. Monitor w/ camera & delta pressure
Batch Chlorination System	Clear fouling during idle periods
Delta Pressure	Alert
Delta Pressure	Alert
Inlet Camera	Visual For Screen Blockage
Ammonia Sensor	Alert
Chlorine Sensor	Alert

As shown in Figure 3-152, the remora's cold water system is comprised of the following components:

- Crossover duct and connection to the cold water elbow
- 2 x Condensers
- Cold water Wye (Converger),
- Straight duct
- Cold Seawater pump
- Discharge Diffuser

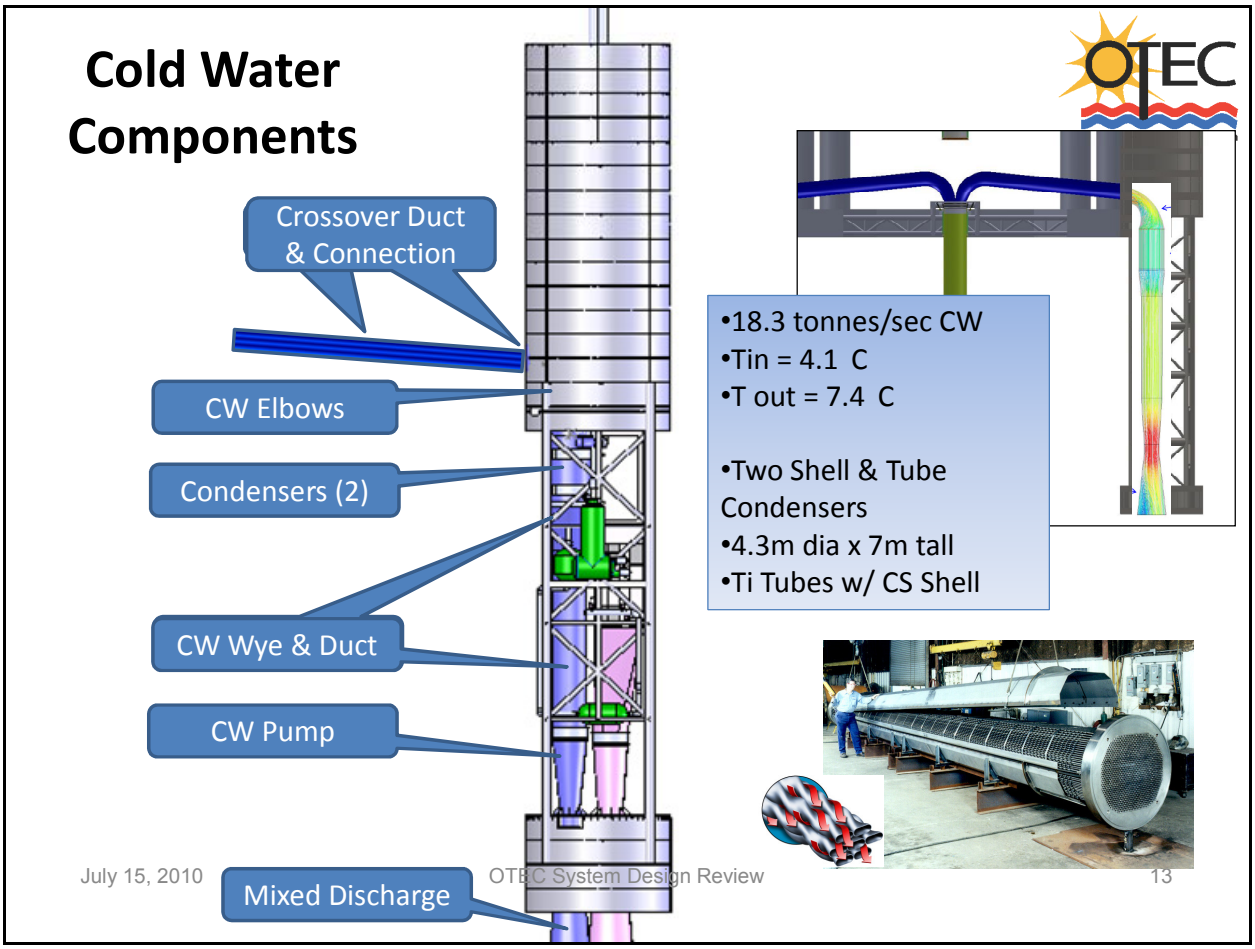


Figure 3-152. Major components and parameters of cold water system

Of course, the entire cold water system also includes the cold water (CW) intake, the Cold Water Pipe, and the Cold Water Pipe termination to the crossover duct. The first item listed in the table deserves discussion. Experience since 1993 at Kona suggests that relatively small amounts of deep biota are entrained by the unscreened cold water intakes. Because the intakes are deep, it seems no CW Intake Screen is needed. Because an intake screen is inaccessible, it is an important issue that requires further study.

The "Strainer" decision listed in the table is directly related to the cold water intake screen issue. If an intake screen is (preferably) not installed, then the relatively low velocity area directly above both condensers should be equipped with a strainer to prevent occasionally large entrained biota before it impinges onto the condensers tubes. This area can be monitored with a low-light video camera. In the probably rare event the strainer needs cleaning, it could be accomplished via ROV, or by a diver team. Suitable access methods for both options should be designed for the ductwork.

3.3.2.1.4.1 Condenser Heat Exchanger

Each remora will use two shell and tube condensers. Selection of these condensers was based upon the following criteria:

- Service life of 10+ years after two-year testing period;
- Proven manufacturing capabilities for delivery of condenser between 2013 and 2014;
- Vertical orientation with deep-ocean seawater flowing down from top;
- Total foot print (single or multiple units) not to exceed 25 m^2, length not to exceed 7 m;
- No routine chlorination for biofouling control, with a back-up system for chlorination during start-up and extended shutdown;
- Condensers to be mounted for vertical position, with supports to be provided for transportation of the remora in a horizontal position; and
- Potential for performance enhancement and cost reduction for commercial OTEC plants.

Design Approach

On the basis of the state-of-the-knowledge, the following condenser designs were evaluated.

- Brazed plate-fin heat exchanger with extruded water passages
- Shell and tube heat exchangers with titanium plain and enhanced tubes
- Shell and tube heat exchanger with aluminum plain and enhanced tubes applying Friction Stir Welding (FSW)
    - Shell and tube heat exchanger with titanium twisted was selected for the pilot plant with spirally indented enhanced tubes as an alternate design option

Justification for the design approach as follows.

- The historical corrosion data show that pitting corrosion of AL-3003 exposed to deep-ocean seawater is more severe than when exposed to surface warm seawater.
- There is no credible corrosion data to qualify brazed AL-3003 joints for condenser.
- Propensity of pitting corrosion of AL-5052 and AL-6063 alloys is relatively low. However, these alloys cannot be brazed or extruded for manufacturing plate-fin heat exchangers. They will be used for shell and tube heat exchangers with conventional welding or FSW.
- Based on the available corrosion data, twisted-tube or spirally indented AL-6063 tubes with FSW would be likely candidates for commercial OTEC plants.
- Use of twisted tubes or spirally indented titanium tubes in the pilot plant will provide performance data that may show advantages for commercial scale OTEC heat exchangers.

Design parameters were derived from the OTEC Power Cycle analysis. E3Tec's in-house performance prediction methods were used to calculate the individual heat transfer coefficients and pressure drops. The design datasheet is presented in Figure 3-153. A schematic of one unit is presented in Figure 3-154. A similar design datasheet is prepared for the alternate design option and is provided in Appendix 3.3-32.

HEAT EXCHANGER SPECIFICATION SHEET

Page 1

SI Units

Prepared by E3Tec Service, LLC

			Job No.				
Customer			Reference No.				
Address			Proposal No.				
Plant Location	Hawaii		Date	7/28/2010	Rev	2	
Service of Unit	Ammonia Condenser		Item No.				
Size	4100 x 5840 mm	Type AEL	Vert. Connected In		2 Parallel	1 Series	
Surf/Unit	21597 m2	Shell/Unit	2	Surf/Shell	10798 m2		

PERFORMANCE OF ONE UNIT

Fluid Allocation		Shell Side		Tube Side	
Fluid Name					
Fluid Quantity, Total	kg/s	212.0		18,330	
Vapor (In/Out)		203.50			
Liquid		8.50	212.00	18,330	18,330
Steam					
Water					
Noncondensables					
Temperature (In/Out)	C	9.60	9.50	4.10	7.4
Density	kg/m3	4.790	625.3	1028	1028
Viscosity	cp	0.01	0.166	1.63	1.63
Molecular Weight, Vapor					
Molecular Weight, Noncondensables					
Specific Heat	kJ/kg-C	2.41	4.68	4.00	4.20
Thermal Conductivity	W/m-C	0.024	0.525	0.57	0.57
Latent Heat	kJ/kg	1235.7	1235.9		
Inlet Pressure	kPa	607.80			
Velocity	m/s	1.02		1.31	1.44
Pressure Drop, Allow/Calc	kPa	5.00	< 2	25.0	24.7
Fouling Resistance (min)	m2-K/W			0.0090	

Heat Exchanged MW	240	MTD (Corrected)	3.52 C		
Transfer Rate, Service	3170 W/m2-K Clean	3260 W/m2-K	Actual	3170	W/m2-K

CONSTRUCTION OF ONE SHELL

Sketch - tube

			Shell Side	Tube Side
Design/Test Pressure		kPaG	1167 / Full Vacuum + 4 bar external pressure	1167 External pressure/Full Vacuum
Design Temperature		C	-28	-28
No Passes per Shell			1	1
Corrosion Allowance		mm		
Connections	In	mm	1 @ 1500.00 with vapor distributor	Buyer to specify
Size &	Out	mm	1 @ 1200.00@ 400 to 500	Buyer to specify
Rating	Intermediate		@	@



Tube No.	39786	OD 15.875 mm	Thk(Avg) 0.559 mm	Length 5.84 m	Pitch 18.7 mm Layout 60
Tube Type	Twisted			Material TITANIUM-GRADE 2	
Shell	ID 4100 mm	od 4170	mm	Shell Cover	
Channel or Bonnet				Channel Cover	
Tubesheet-Stationary				Tubesheet-Floating	
Floating Head Cover				Impingement Plate None	
Baffles-Cross	Type NONE	%Cut (Diam)		Spacing(c/c)	Inlet mm
Baffles-Long		Seal Type			
Supports-Tube		U-Bend		Type	
Bypass Seal Arrangement		Tube-Tubesheet Joint			
Expansion Joint		Type			
Rho-V2-Inlet Nozzle	kg/m-s2	Bundle Entrance		Bundle Exit	kg/m-s2
Gaskets-Shell Side		Tube Side			
-Floating Head					
Code Requirements				TEMA Class	
Weight/Shell				Bundle	MT

Remarks:

Figure 3-153. Condenser Design Datasheet

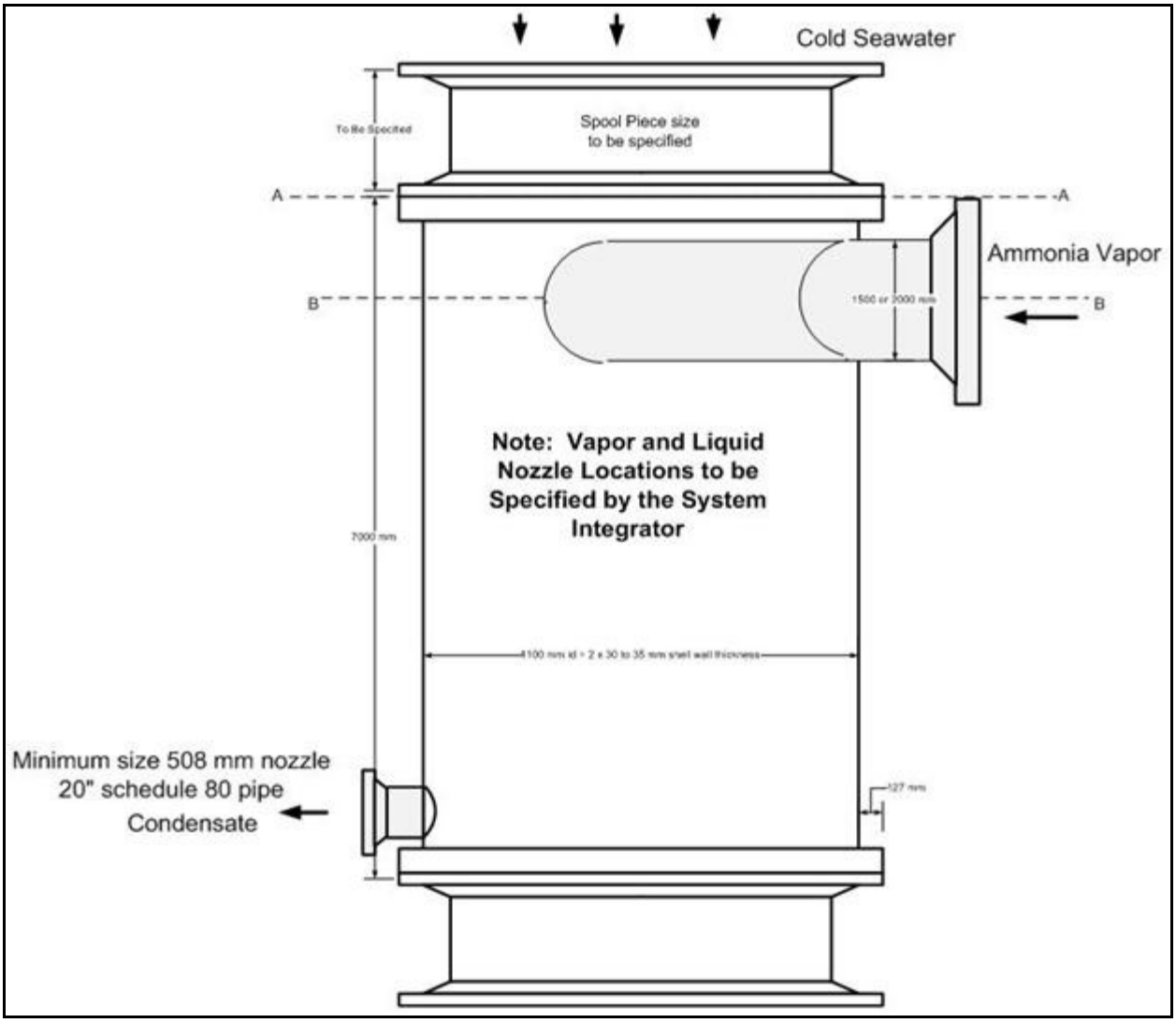


Figure 3-154. Schematic Diagram of Condenser

Deep-ocean cold seawater enters the condenser from top and the seawater pump is located down-stream of the condenser. Ammonia vapor from the turbine flows down the remora and divides into vapor manifolds attached to the condenser. The vapor manifold is designed to minimize the nozzle velocity to reduce pressure drop and possible impinging of ammonia liquid droplets on tubes at high velocity.

The condensation process is gravity controlled with relatively low pressure drop as shown in the design datasheet. Appendix 3.3-34 shows additional design details.

The material of construction is as follows:

- Tubes Titanium Grade 2
- Shell Carbon steel
- Tube sheet Carbon steel with titanium cladding
- Nozzles Carbon steel
- Supports Carbon steel

Conventional shell and tube heat exchangers are supported by saddle support for horizontal installations and by lug supports for vertical installations. Schematics of such supports are shown in Appendix 3.3-34. However, condensers will be in horizontal positions during the transport of remora to the platform, and then connected in vertical position. Therefore, a combination of saddle and lug support is required for the condenser.

3.3.2.1.4.2 Cold Water Ducting

The cold water ducting is similar to the warm seawater ducting; hence the reader is referred to the earlier section for general information. The primary unique feature here is that instead of the warm water intake, the cold seawater enters the remora from the cold seawater crossover duct connected to the top termination of the CWP. This ducting arrangement requires some design compromises for the overall system, because the desire for a large and efficient seawater flow path conflicted with the need to minimize entrained volume (and loading) of the crossover duct. The arrangements considered are shown in Figure 3-155.

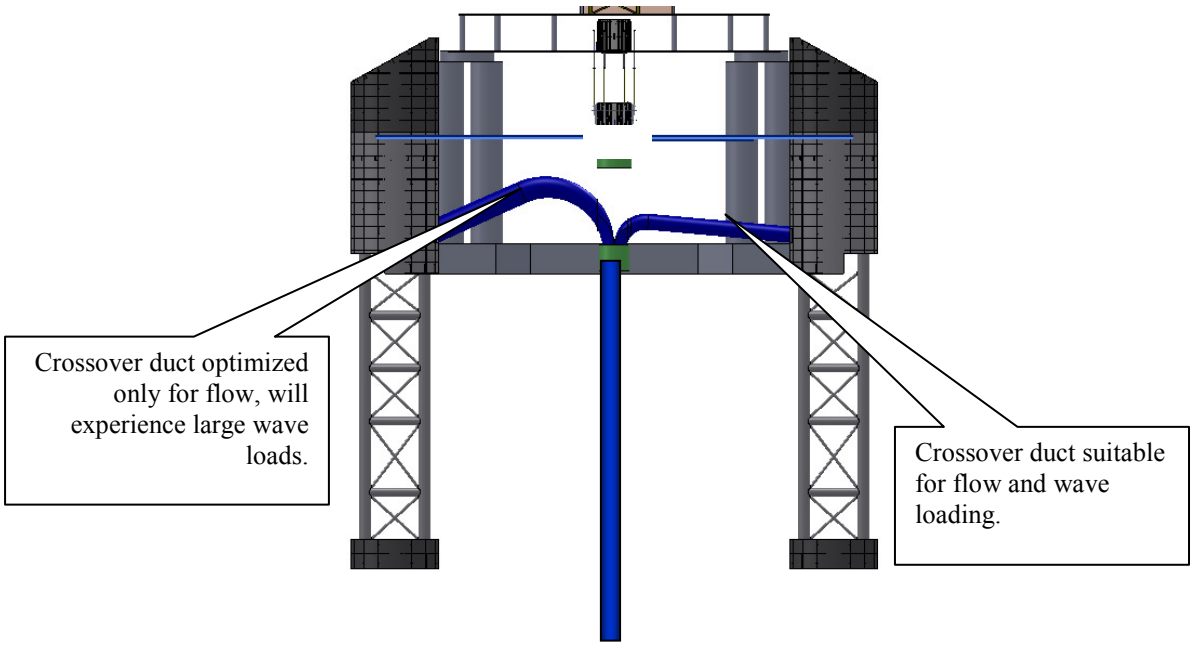


Figure 3-155. Two alternate cold seawater crossover duct arrangements

Navatek modeled and Makai evaluated the best solutions for several of these necessary compromises. The work is summarized in Figure 3-156. More detail of these evaluations is provided in Figure 3-157 though Figure 3-162.

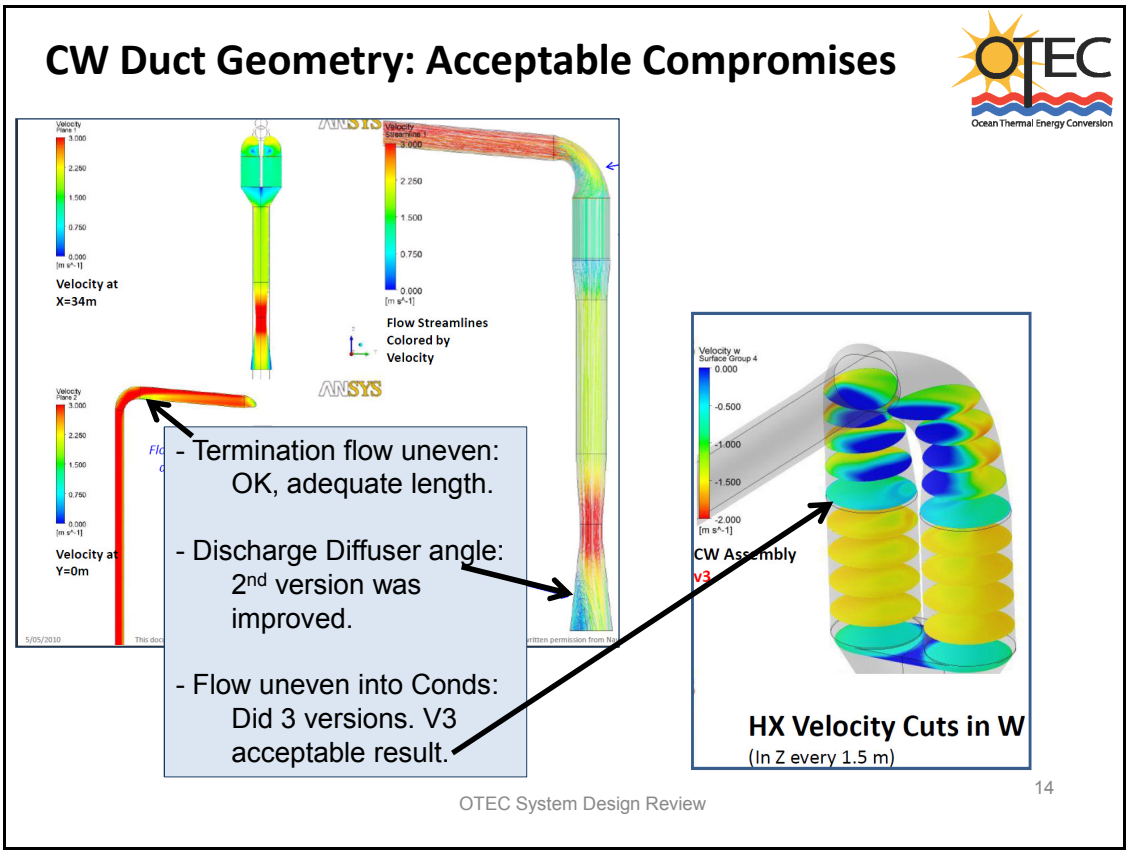


Figure 3-156. Summary of CW duct optimization work

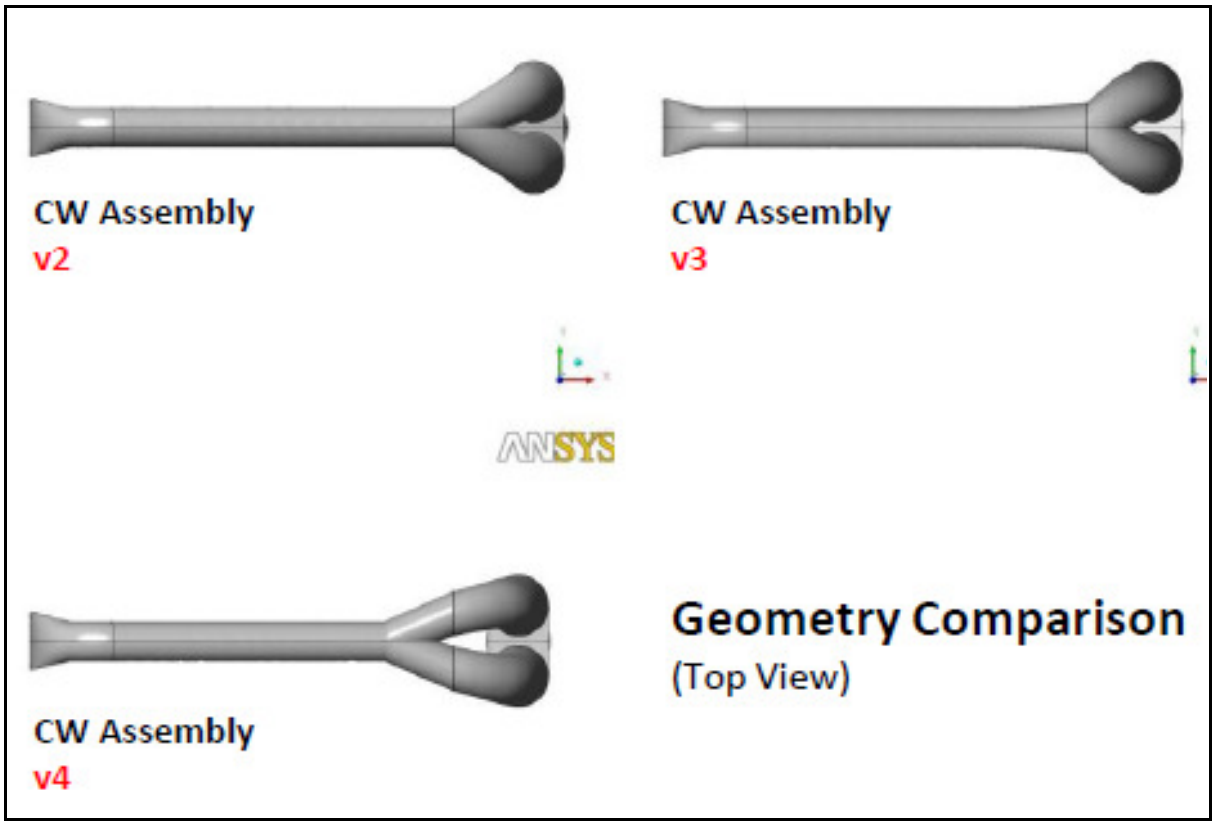


Figure 3-157. Condenser Elbow arrangements

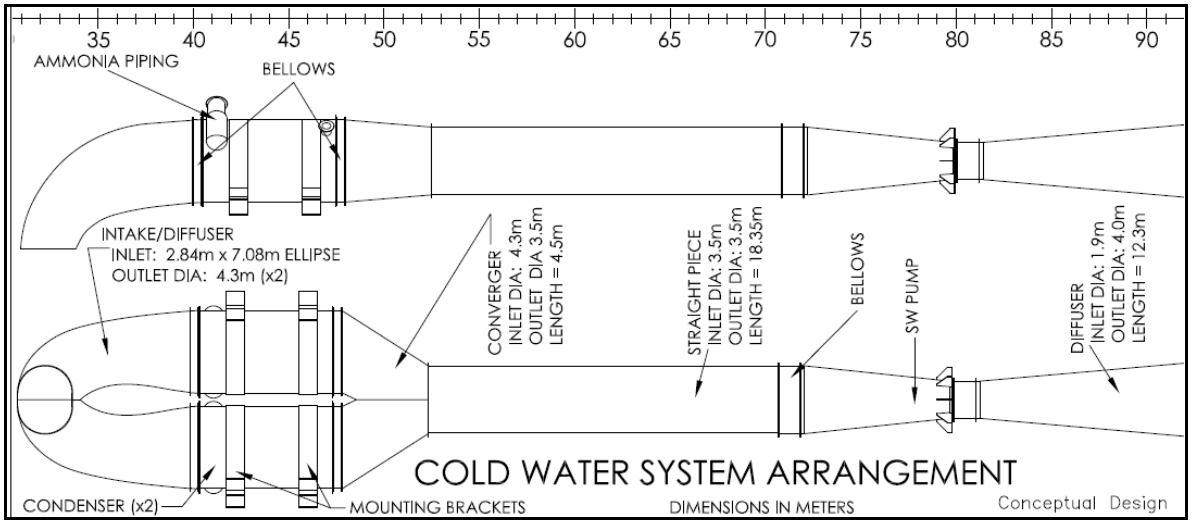


Figure 3-158. Arrangement of Cold Water Ducting

The cold water intake elbow is a particularly complicated piece of ducting since it performs three functions: splits the water from the CWP into two separate streams; turns the water 90°; and slows the water velocity before entering the condensers. To improve the efficiency of the power production, a study of several different cold water intake geometries was conducted using computational fluid dynamics (CFD) with the objective of designing a cold water intake that provided evenly distributed, low velocity flow into the condensers. The reports documenting the CFD study are provided in Appendix 3.3-35.

A perspective view of the cold water intake ultimately used is presented in Figure 3-159. As can be seen, use of this particular intake geometry requires a modification to the discharge end of the cold water crossover duct. The cold water pipe diffuser (discharge end) was redesigned using the same diffuser criteria from Blevins as was used for the warm water diffuser (and the cold water diffuser). The performance of the resulting cold water pipe diffuser is shown in Figure 3-147.

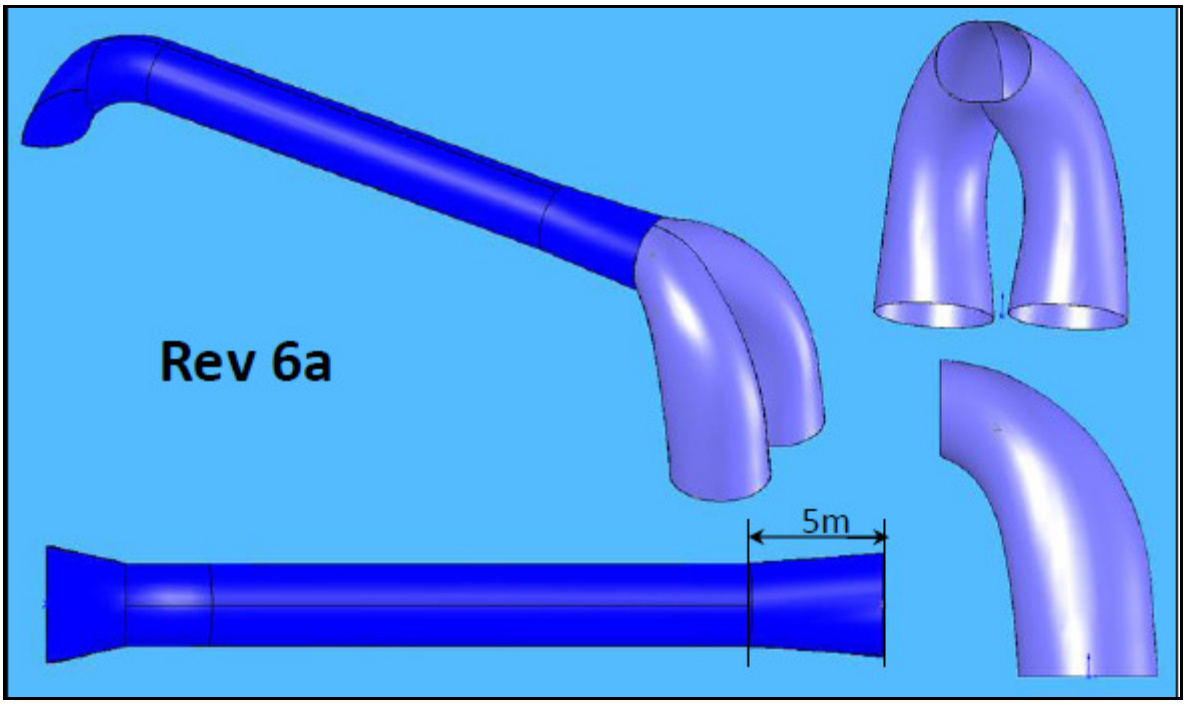


Figure 3-159. Cold Water Intake

Examples of some of the CFD results are presented in Figure 3-160, Figure 3-161, and Figure 3-162. The CFD study was also used optimize the performance of the cold water diffuser. The cold water diffuser was ultimately designed using the Blevins' methodology as was used for the warm water diffuser and the CWP. Performance of the cold water diffuser is plotted in Figure 3-147 as well.

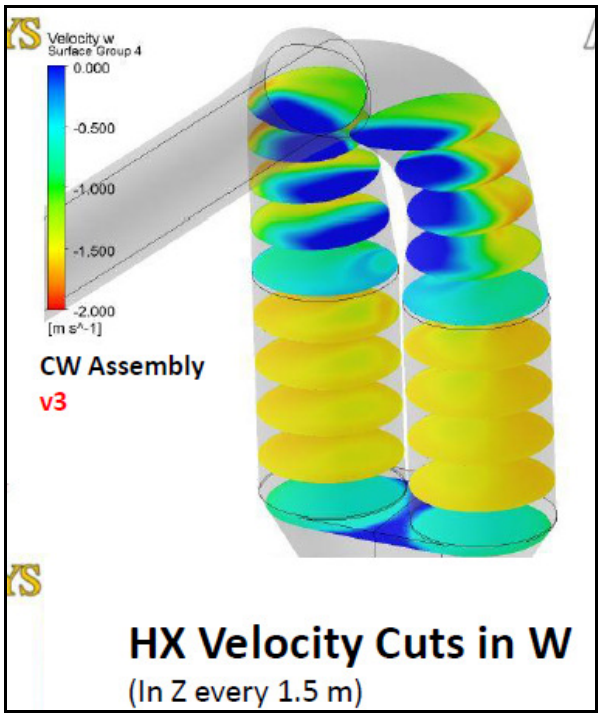


Figure 3-160 CFD Analysis--Velocity Cuts

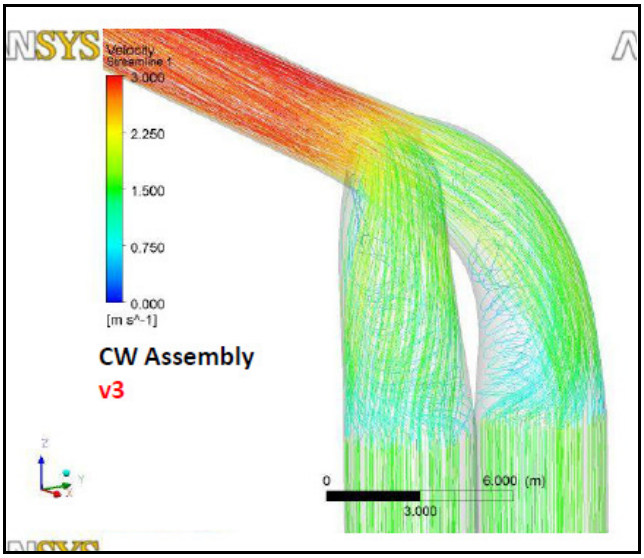


Figure 3-161. CFD Study - Velocity Streamlines

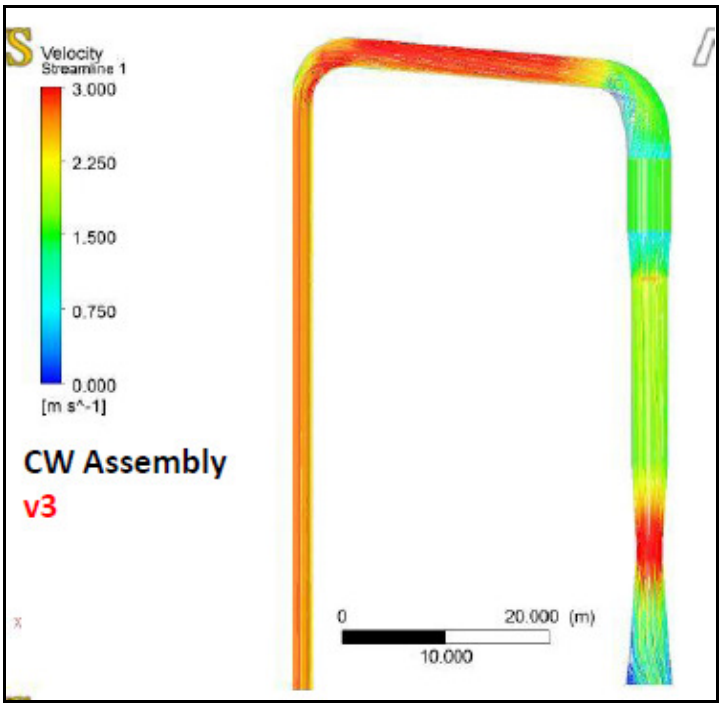


Figure 3-162. CFD Study-Cold Water System Performance

Lessons learned from the CFD study include:

- Flow in the cold water pipe where it makes a 90° turn at the CWP termination is uneven, with slower flow on the inside of the elbow. However, the crossover duct is long enough that the cold water flow velocity evens out before it reaches the cold water intake on the remora.
- Flow in the original cold water elbow showed turbulence and a great deal of velocity distribution prior to entry into the condensers. Reshaping the elbow (and the discharge end of the crossover duct) improved the flow into the condenser.
- There was uneven flow velocity through the original cold water diffuser. Reshaping the diffuser improved the discharge flow.

3.3.2.1.4.3 Cold Water Pumps

The arrangement of the cold water pumps is very similar to the warm seawater pumps. The seawater pumps require an adjustable sleeve to withstand the pump's suction pressure, which is larger for the cold water flow, while allowing retraction and adjustment of the ductwork for pump removal. The reader is referred to the warm water pump sections for more detail of pump installation.

Cold Water Pump Design Conditions

- Design Point: 17.8m³/s @ 5m Total Dynamic Head
- Density of Water: 1028kg/m³, Temperature: 4˚C

3.3.2.1.4.4 Cold Water Corrosion Control

The condenser baseline consists of two shell & tube condensers, each 7m tall by 4.3m in diameter. The inlet water temperature is 4.1°C and the outlet temperature is 7.4°C. Titanium tubes have been selected as the primary heat exchanger element. Galvanic corrosion between the tubes, tubesheets and water boxes will be considered in the final FEED design. If the final shell of the heat exchangers is titanium, then galvanic corrosion between the condenser shell and other remora components must also be considered. If the interior waterboxes are to be cathodically protected to mitigate galvanic corrosion, this cathodic protection must be carefully controlled to prevent hydriding of the titanium tubes. Details of the specific cold water corrosion management measures will be completed as part of the FEED phase of this design.

3.3.2.1.4.5 Cold Water Instrumentation and Control

The instrumentation for the cold water subsystem consists of temperature, pressure, and flow sensors. The controls for the cold water subsystem consist of the cold water pump. Table 3-52 shows each of the instrument locations, with the numbered position corresponding to the numbers in Figure 3-138.

Table 3-52. Cold Water Subsystem Instrumentation

Sensor Type	Location	Rationale	Redundant
Temperature	7.3	Performance Calculations	Yes, one at the inlet to each unit
Pressure	7.3	Performance Calculations	Yes, one at the inlet to each unit
Temperature	7.2	Performance Calculations	Yes, one at the outlet to each unit
Pressure	7.2	Performance Calculations	Yes, one at the outlet to each unit
Flow	7.2-7.1	Performance Calculations	Yes
Delta Pressure	7.3-7.2	Alerts	Yes
Delta Pressure	7.1-Exit	Alert	Yes
Delta Pressure	7.3-CWP	Alert	Yes
Ammonia Sensor	7.1	Alert	No

A controls analysis was performed that drove requirements for this subsystem along with the working fluid and warm water subsystems. The results are discussed in sections 3.3.4.2 and 3.3.4.2.1.

3.3.2.2 Cold Water Pipe (A2200)

3.3.2.2.1 Cold Water Pipe Instrument and Control

Coldwater pipe Instrumentation and control is covered in detail in section 3.3.4.2.2.

3.3.2.2.2 Pipe Subsystem

A detailed description of the CWP subsystem can be found in the Technology Development Report, Section 4.1, Cold Water Pipe.

3.3.2.2.3 Connection Subsystem

A detailed description of the CWP Connection subsystem can be found in the Technology Development Report Section 5.6, Pilot Plant Platform Connection and Section 6.13, Platform Interface.

3.3.2.2.4 Termination Subsystem

A detailed description of the CWP termination can be found in the Technology Development Report Section 5.3, Cold Water Pipe Termination Design.

3.3.2.3 Electrical Generation Element (A2300)

The electrical generation element consists of the OTEC ammonia turbine, electrical generator, controls, and their associated auxiliaries. This element serves as the interface between the ammonia power cycle and electrical power delivery element. The state change from vapor→mechanical→electrical power occurs within this element. Compared to other system elements, electrical generation has relatively low technical risks associated with it. This element leverages existing technology from the commercial field of electric power production and offshore oil & gas. The electrical generator, in particular, is of low technical risk. Options for ammonia turbines currently exist, however they are not optimized for an OTEC application. Likewise, power control equipment such as the turbine governor and valves can be expected to have longer response times and time constants than contemporary thermal power plants. Some of these constraints are inherent of the OTEC resource and power conditioning architecture; others can be optimized through system maturation. A functional block diagram of the electrical generation element, with external interfaces is shown in Figure 3-163.

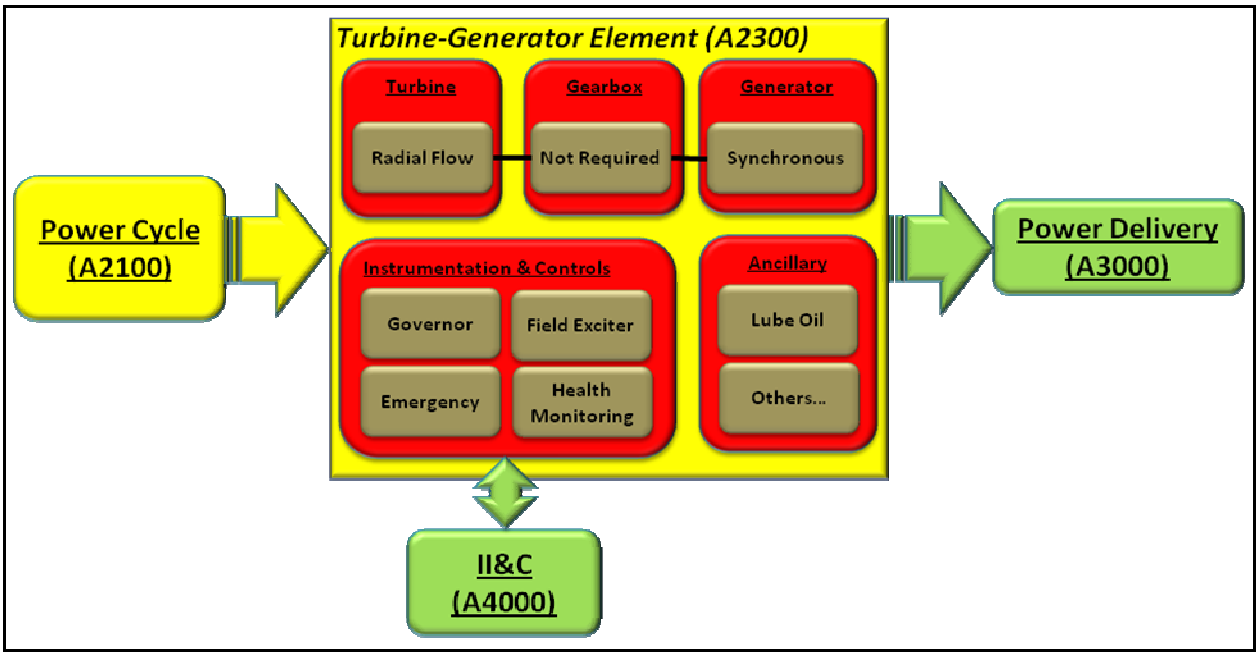


Figure 3-163. Functional Block Diagram for the Electrical Generation Element

The following subsections will investigate the subsystem components of the electrical generation element. The key requirements for the turbine generator are listed on Table 3-53. The trade study results are in

Table 3-54.

Table 3-53. Turbine-Generator Element Key Requirements

Requirement	Source	Rationale
The turbine inlet ammonia mass flow rate shall be between 196 kg/s to 212 kg/s (average condition 203 kg/s)	Derived	Turbine shall provided optimal power output within power cycle operating envelope
The turbine inlet ammonia saturation pressure shall be between 802 kPa to 912 kPa (average condition 864 kPa)	Derived	Turbine shall provided optimal power output within power cycle operating envelope
The generator shall be a 3-Phase, AC, synchronous machine.	External	Standard generator choice. >97% of all electricity generation comes from synchronous generators.
The generator shall have a synchronous frequency of 60 Hz	External	Standard U.S. grid frequency. Frequency for Oahu grid.
The generator shall be rated for a minimum 11 megavolt amperes (MVA).	Derived	Minimum generator size needed to supply maximum OTEC power at worst case 0.8 power factor

Table 3-54. Turbine-Generator Trade Study Results

Trade Study	Results and Rationale	Impact
Turbine Sizing Options: 7-9 MW.	Turbine generator sized for 1 standard deviation of maximum annual seasonal output, which is 8.7 MWe. Rationale: turbine-generator sized such that it can provide maximum power throughout the range of environmental conditions.	Power Generation System, Turbine-Generator Element
Generator Specification Options: Numerous	Preliminary generator requirements defined: synchronous machine, 13.8 kV, 11 MVA, 3600 RPM, 0.8 load PF, brushless excitation, etc. Rationale: Generator requirements selected such that they comply with IEEE & industry standards, including ANSI/NEMA (National Electrical Manufacturers Association), while meeting the specifications defined.	Power Generation System, Turbine-Generator Element
Number of Power Cycles Options: 1 or more	Single stage turbine-generator selected. Rationale: Simplifies turbine-generator layout, as well as power cycle piping layout.	Power Generation System, Turbine-Generator Element

3.3.2.3.1 Electrical Generation Instrument and Control

The control system for the electrical generation is grouped into three categories: Power Flow, Health/Status, and Emergency Controls. Each category serves an important role in maintaining the proper operation of the electrical generation element. The categories are expanded on in the following subsections.

3.3.2.3.1.1 Power Flow

Power flow controls include the turbine-governor and generator-field exciter. These control devices regulate the flow of power from the power generation cycle into the power delivery element. The governor regulates the real power produced by the turbine. The field exciter regulates the terminal voltage of the generator and the reactive power being generated. The turbine-governor regulates the speed and torque (i.e. real power) on the drive shaft between turbine-generator. To meet the energy needs of the platform and grid, the turbine will maintain 60 Hz rotor frequency. It is assumed both of these items will come packaged as part of the turbine-generator solution. The field exciter will likely not require any customization for an OTEC application. The turbine-governor will likely require some customization to adjust its control parameters to the OTEC resource controllability.

3.3.2.3.1.2 Health/Status

The health status function monitors the health of the turbine-generator from the ammonia vapor loop to the electrical system. Health signals that are being measured include the ammonia pressure and mass flow, thermal readings from the turbine generator, shaft speed, and electrical output. Any abnormal conditions picked up by the health status system will initiate the corrective actions within the power flow controls. If the conditions are not resolved, emergency controls are initiated to prevent equipment damage and for personnel safety.

3.3.2.3.1.3 Emergency Controls

Emergency controls take action to prevent catastrophic failure in the system. The control involves closing valves in the ammonia loop and opening the generator breaker. Types of events that can cause the emergency controls to initiate can include ammonia leaks, overheating equipment, faults on the electrical system, among other possible scenarios. Operation of the generator breaker occurs through the local digital relay. The relay measures numerous electrical and temperature signals from the generator and the line to check for fault scenarios. Faults picked up by the relay will initiate a trip command to the generator breaker. The electrical drawing in Appendix 3.3-36, sheet 3, shows the protection system attached to the generator to protect the turbine-generator element from electrical faults. The emergency controls are at a pre-FEED level of maturity. They will be further refined in the next phase of the design.

3.3.2.3.2 Turbine Subsystem

The ammonia turbine converts the vapor energy harvested in the power cycle into rotating mechanical power. There are two possible configurations for the ammonia turbine, either axial flow or radial flow. With an axial flow turbine, vapor enters through one end of the turbine and is passed horizontally through the turbine blades stages where it is discharged on the opposite end of the turbine. Whereas in a radial flow turbine, vapor enters through the radius of turbine wheel and discharges parallel to the turbine shaft. Figure 3-164 and Figure 3-165 show the axial and radial flow configurations, respectively. The radial flow turbine option was selected for the OTEC pilot plant. Reasons for selecting the radial option include higher efficiency, low technical risk, and satisfying OTEC turbine requirements. Axial flow may be a better option for commercial plants given that they can overcome wheel diameter limitations by adding more stages in parallel. Given that the efficiency can range from low 80% to up to 90% in practical turbines, there is room for potential greater gains in efficiency. Obtaining a small percentage increase in turbine efficiency can have a major impact on system efficiency and capital cost. Increasing turbine efficiency can result in a reduction in heat exchanger area, ammonia, seawater pumps, and other system components.

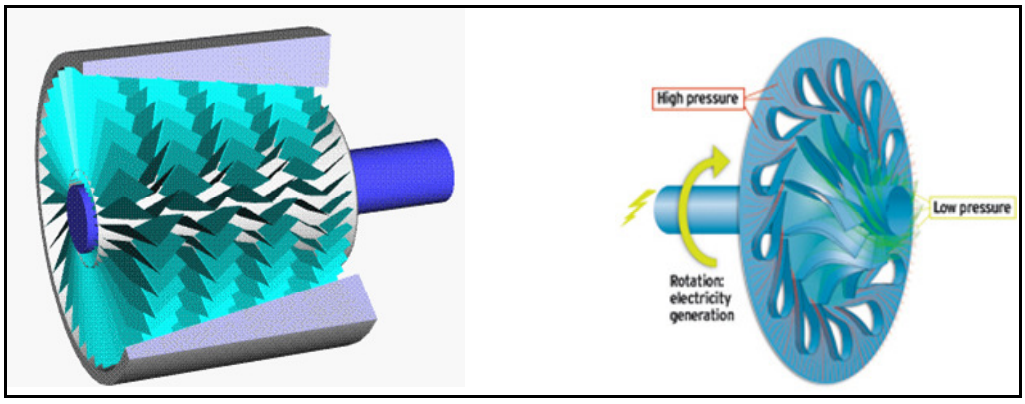


Figure 3-164. Axial Flow Turbine

Figure 3-165. Radial Flow Turbine

3.3.2.3.2.1 Turbine Baseline

The turbine baseline for the pilot plant is an ammonia turbo-expander (i.e. radial flow turbine). There are a handful of possible vendors for the turbine. General Electric (GE) Oil & Gas was contacted during the contract because of their experience in turbo-expanders for offshore environments. The turbine referenced for the Pre-FEED design is the GE Frame 160 turbo-expander. The general specifications for the baseline turbine are given in Table 3-55. The turbine design for the pilot plant will be further defined during the next phase of the design. The full performance data for the turbine-generator is given in Appendix 3.3-36.

Table 3-55. Turbine Baseline Specifications

Parameter	Nominal Value	Unit	Deviation
Type	Radial	-	-
Inlet Pressure	862.1	kPa	800-909.7
Inlet Temperature	20.2	°C	17.9-21.9
Mass Flow Rate	203	kg/sec	196-212
Rated Power	7.7	MW	5.77-9.13
Efficiency	86	%	83-86
Synchronous Speed	3600	RPM	+/- 6
Impeller Material	7050 Al	-	-
Casing Material	SA216 Carbon Steel	-	-

3.3.2.3.3 Generator Subsystem

The electrical generator for the pilot plant is one of the lowest technical risks items for the power generation system. There currently exist generators options in size range from kilowatt to gigawatt scale. There are two common generator types; induction machine and synchronous machine. Induction machines have historically been utilized as motors for a variety of applications. Their utilization as generators comes from areas where constant speed is not possible (i.e. wind turbines). Synchronous machines have been the standard generator of choice for power production for the past 100 years. Approximately 97% of the electricity produced in the U.S. comes from synchronous generators. They are utilized in virtually all fossil, nuclear, geothermal, biomass, and hydro power plant installations. The OTEC plant baseline is a synchronous generator due its ability to operate at a fixed speed. The efficiency of the generator is between 97-98% through the seasonal variation. No OTEC specific technical challenges currently exist in this area to impede the development or procurement of the turbine for the pilot plant. There are numerous vendors available for the pilot plant generator. This includes ABB, Siemens, Brush, and Mitsubishi among other vendors. Brush was contacted during the contract because of their experience in generators for offshore Oil & Gas applications. The material referenced in this report for the generator was provided by Brush Turbogenerator.

3.3.2.3.3.1 Generator Baseline

The generator specifications are shown in the trade study results in Table 3-56. The candidate generator can be manufactured by a wide range of manufacturers. Brush was selected for reference for the Pre-FEED generator specification. The baseline generator complies with ANSI/NEMA electrical standards. The reference Brush generator is rated for 11.76 MVA in capacity. While this exceeds the specification, it is selected for its commercial availability. The full performance data for the turbine-generator is given in Appendix 3.3-36.

Table 3-56. Generator Baseline Specifications

Parameter	Nominal Value	Unit	Deviation
Type	Synchronous	-	-
Output Power	9.6	MVA	7.2-11.4
Efficiency	97.5	%	97-98
Terminal Voltage (L-L)	13.8	kV	9-19.5
Frequency	60	Hz	+/- .1
Synchronous Speed	3600	RPM	+/- 6
Power Factor	.8	-	.8-.95
Cooling	TEAAC (Totally Enclosed Air to Air Cooled)	-	-

3.3.2.3.4 Turbine-Generator General Arrangement

The general arrangement of the turbine-generator skid is shown in Figure 3-166 and Figure 3-167. The arrangement was supplied by GE Oil & Gas as part of their budgetary proposal. The initial estimate for the skid weight is approximately 56 metric-tons. The weight and footprint of the system will be further refined during FEED.

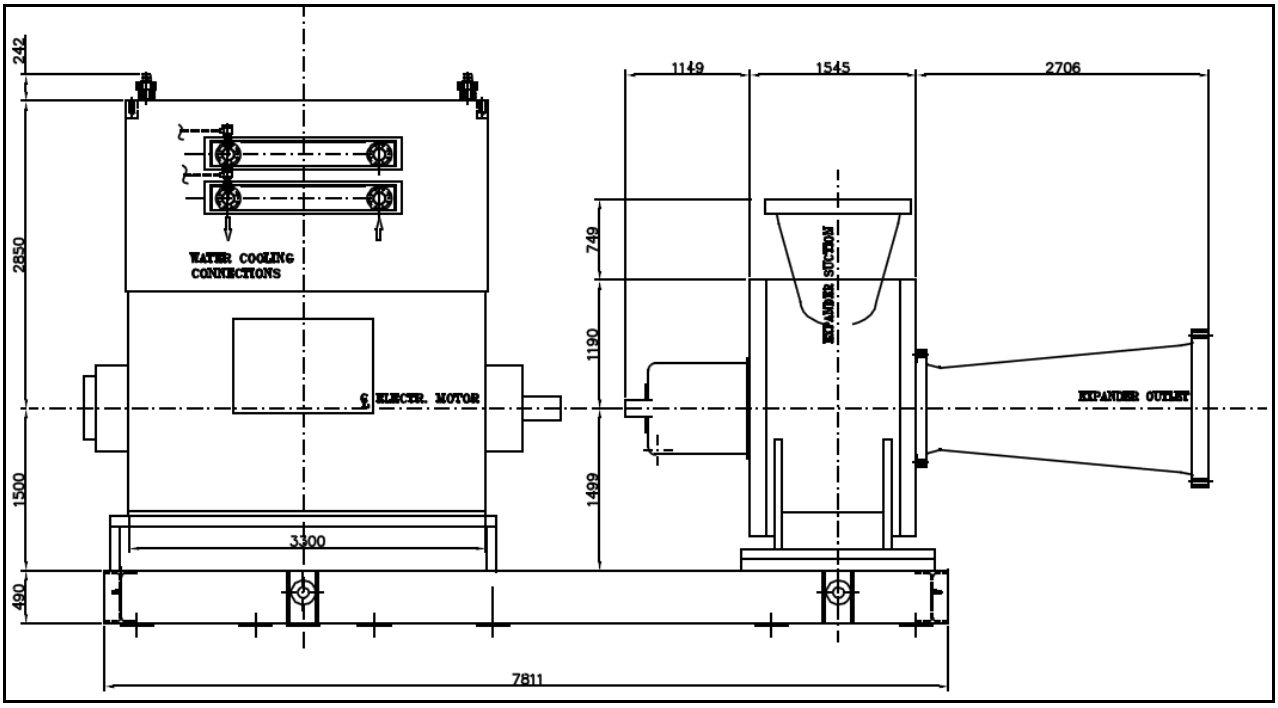


Figure 3-166. Turbine-Generator Skid Side View (from GE Oil & Gas)

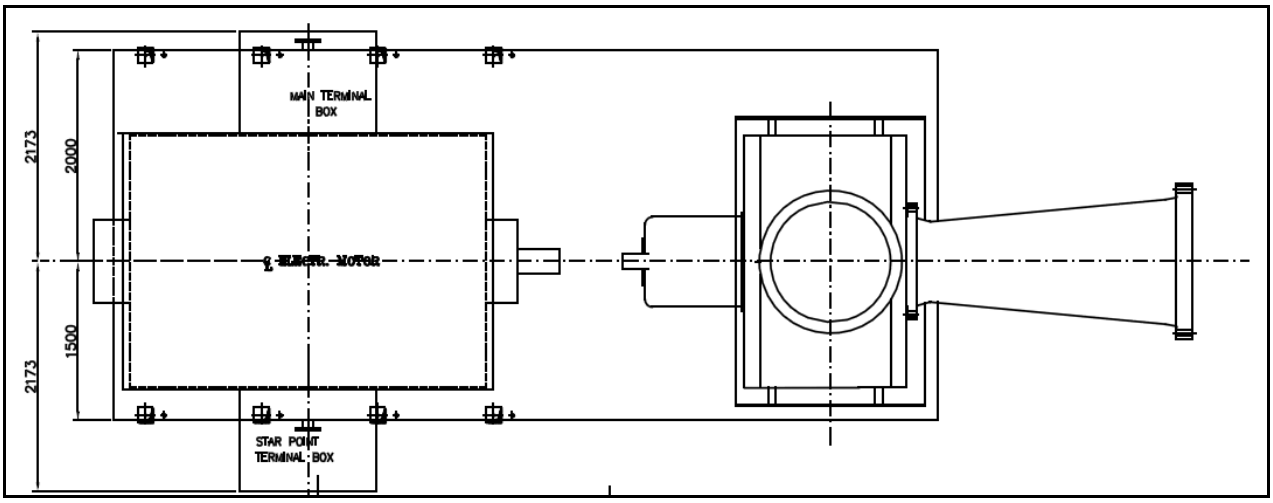


Figure 3-167. Turbine-Generator Skid Top View (from GE Oil & Gas)

3.3.2.3.5 Electrical Generation Ancillary Equipment

The ancillary equipment required to support the operation of the turbine-generator includes the lube oil console, turbine-generator skid, cooling equipment, and other support auxiliaries. The lube oil console contains the system required to keep the bearings on the turbines cooled and well lubricated during operation. The lube-oil console general arrangement is shown in Figure 3-168. The initial estimate for the lube oil weight is 12 metric-tons. This is usually packaged with the complete turbine-generator solution. Likewise, the cooling system for the generator is packaged as part of the generator assembly. The cooling system requires external interface to a cooling water loop or a forced air cooling loop, depending on configuration. For the current baseline, it is assumed the generator will use an air-cooled system. This will be further refined and investigated during FEED.

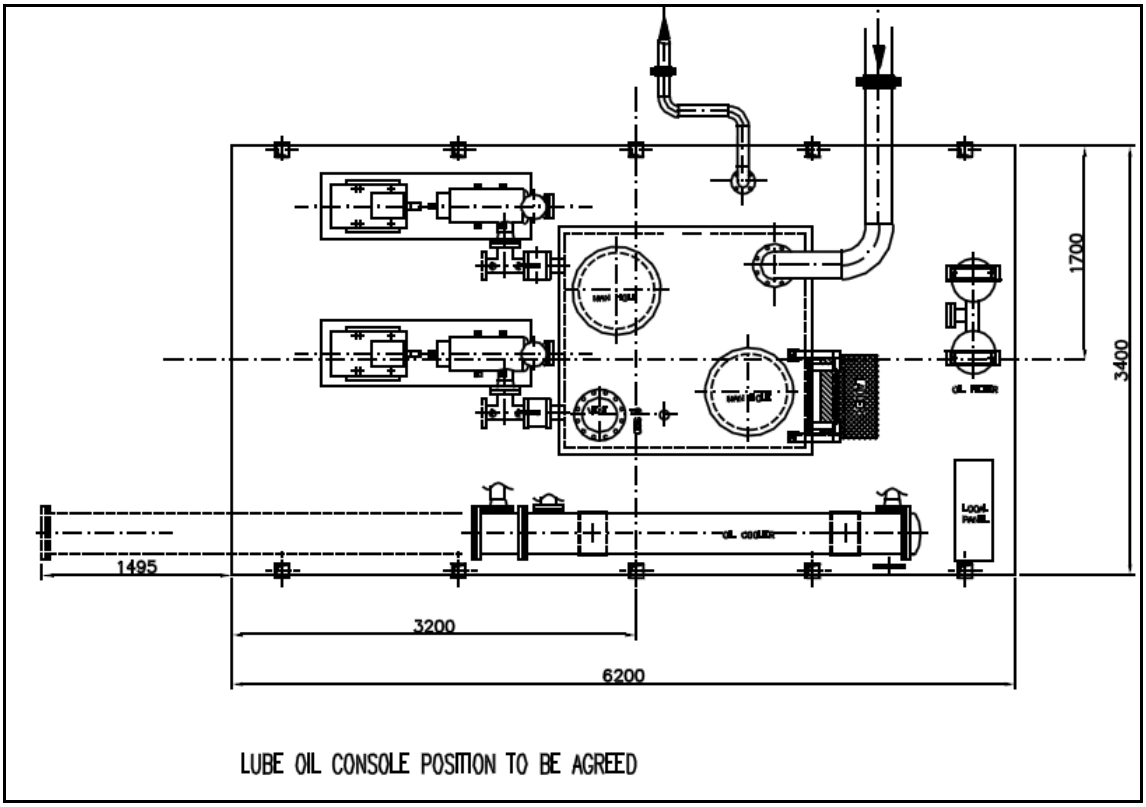


Figure 3-168. Lube Oil Console Top View (from GE Oil & Gas)

3.3.3 Power Delivery Segment (A3000)

3.3.3.1 Electric Delivery Element (A3100)

The power delivery segment encompasses all of the electrical equipment required to condition and deliver the power produced by the turbine-generator to the platform load and the customer power grid. The main hardware components of this section include transformers, switchgear, protective relaying, submarine power cable, and medium voltage cabling. The hardware components for power delivery segment are grouped into 3 subsystems: Platform Substation, Power Transmission, and Onshore Substation. The following sections will cover the hardware for each subsystem. The functional block diagram of the power delivery section is shown in Figure 3-169.

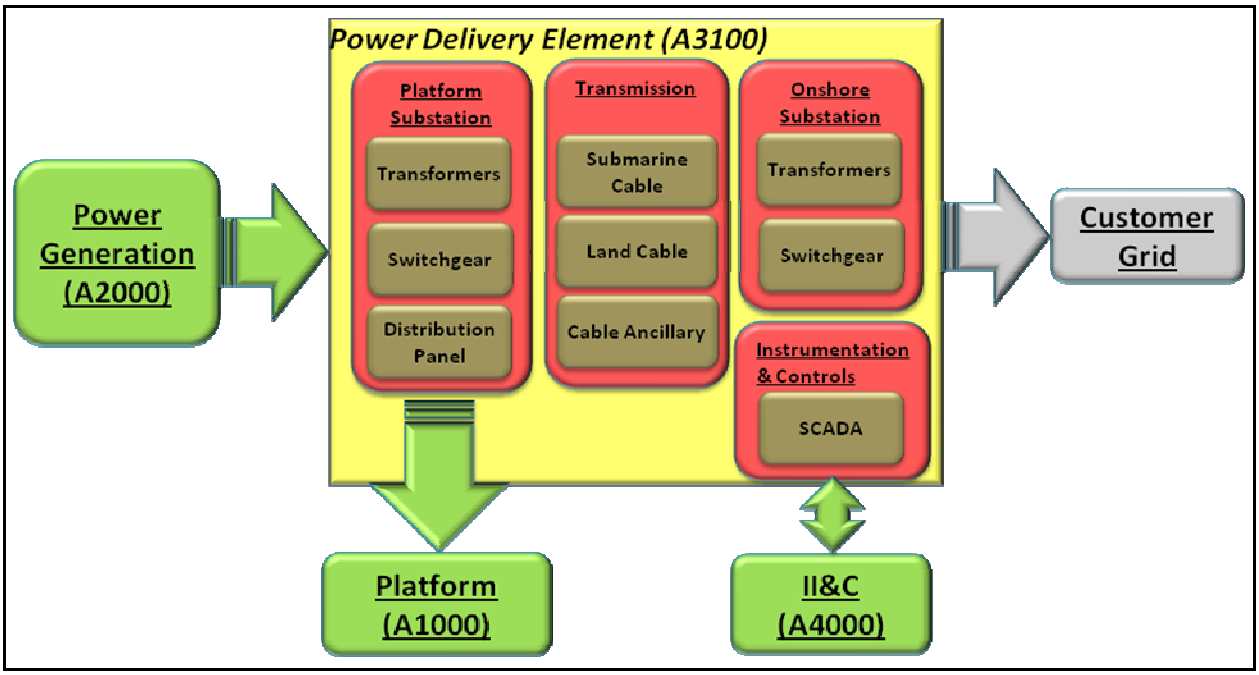


Figure 3-169. Functional Block Diagram for A3100

The designs of the 3 subsystems of the power delivery element are closely interrelated to each other. The interface with the power generation subsystem has been designed as part of the power generation design covered in section 3.3.2.3 and the interface with the platform had been developed in collaboration with the platform design group covered in section 3.3.1. Several informal trade studies were performed throughout the contract to capture these design decisions and the impact that they had on the power delivery element and other elements of the OTEC system. This includes, but is not limited to: Power System Architecture Study, Grid Interface Study, Onshore Landing Study, and Costing Exercise. The key trade study results are captured in Table 3-57 . The trade studies involved literature review, analytical analysis, and vendor interfacing. The results of these trade studies form the basis of design for this element. The

requirements for the Power Delivery Element are contained within each of the subsystems. A logical flow down of requirements from source to specifications is shown in Figure 3-170.

Table 3-57. Power Delivery Trade Study Results

Trade Study	Results and Rationale	Impact
Electrical Standard Options: IEC (International Electro-technical Commission), NEMA	NEMA was selected because it is the standard most commonly applied to U.S. power projects. For the pilot plant this will result in easier interface with the customer and U.S. vendors/subcontractors.	Power Delivery Element, Power Generation
Interconnection Voltage on Platform: 3.3-18 kV	13.8 kV was selected as the interconnection voltage between the generator and platform distribution and transmission subsystem. Selected over lower voltage options to limit line losses and cabling costs due to the long distance between substation and turbine-generator room(s). Selected over higher voltage options for cost savings.	Power Delivery Element, Power Generation
Submarine Cable Voltage: Options: 15-60 kV	Submarine cable voltage of 34.5 kV line-line selected. Thorough analytical study was performed (see 3.3.3.1.2) to evaluate submarine cable efficiency and performance through a variety of voltages. 34.5 kV ultimately selected as it has previously been installed for offshore dynamic installations.	Power Delivery Element
Substation Switchgear Voltages Options: various from <1-60 kV	Voltages Selected: 38 kV, 15 kV, 5 kV, and 480 V. Standard NEMA voltage classes (i.e. U.S. voltages). Switchgear must be rated at or above bus voltages (i.e. 15 kV switchgear utilized for 13.8 kV bus). Simplifies and streamlines component selection and procurement process.	Power Delivery Element, Deployment & Installation
Costing Exercise Options: Size transmission for 5 or 10 MW.	Recommended initially sizing transmission equipment for 10 MW upgrade. Rationale: <$2MM cost increase during pilot phase, $20MM+ cost savings during upgrade.	Power Delivery Element

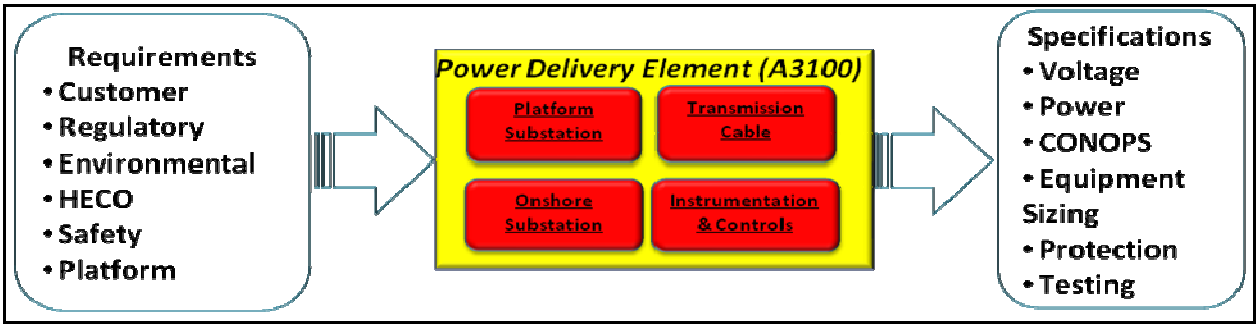


Figure 3-170. Requirements Flow Down

Finally, for the NAVFAC contract, a drawing package containing electrical single-line diagrams and physical layouts was compiled. The single line drawing focuses on the system as represented for the initial 5 MW-net-average pilot phase. Allocations are made within the platform substation section of the drawing for future upgrade to a 10 MW-net-average size plant. The physical layout does show the allocation for the future system upgrade. The complete drawing package is located in Appendix 3.3.1-5 with Power Delivery supplementary information in Appendix 3.3-36.

3.3.3.1.1 Platform Substation Subsystem

The platform substation interfaces the turbine-generator with the platform local load and power transmission subsystem. The platform substation is physically located inside the electrical compartment on the lower level of the platform. The transformer yard, which contains the substation transformers, is located directly above the electrical compartment on the top level of the platform (see Figure A3.3.3-4 in Appendix 3.3-36). The overall power system architecture and physical layout has been designed such that the plant is upgradeable to 10 MW expansion through adding a second bus and transformers in parallel with the initial 5 MW infrastructure. The transmission architecture is initially sized for 10 MW to reduce the cost and complexity for the eventual upgrade of the system. This design implementation is captured in the Power Delivery trade study results. The top level requirements for the platform substation are listed in Table 3-58.

Table 3-58. Requirements for the Platform Substation Subsystem

Requirement	Source	Rationale
Generator bus voltage shall be 13.8 kV line-line AC	Derived	13.8 kV selected eliminate copper bus bar between Turbine-Generator Room and platform substation. Cost savings and risk reduction.
Power Delivery equipment shall be initially sized for the 10 MW upgrade capacity	Derived	$20 MM+ cost savings during upgrade. Allows for fully redundant system operation at 10 MW size.

Requirement	Source	Rationale
Gas Insulated Switchgear shall be utilized for operating voltage >5 kV	Derived	Reduces footprint, increases reliability, reduces life cycle cost, but has a higher capital cost.
Relay protection for all MV equipment	External	For safety and security of plant and personnel
Load bank installed on platform	Derived	Utilized for commissioning and power cycle testing

3.3.3.1.1.1 Platform Switchgear

The platform switchgear handles the operation of circuit breakers for protecting the OTEC plant from faults and for sectionalizing the system. The size of switchgear on the platform ranges from 5 kV to 38 kV, depending on bus selection. The primary switchgear utilized on the platform is 15 kV metal clad. This switchgear is utilized for equipment tied-in at the generator bus voltage, 13.8 kV. Switchgear rated for 5 kV is utilized for the distribution bus for the seawater pumps and low voltage auxiliary system on the platform. Several vendors, both domestic and international, can supply switchgear for the pilot plant. ABB and Siemens have been reference in the Pre-FEED design given their commercially available technology and their readily available technical data sheets. Review of other vendors and further down selection will occur during the next design phase. An informal trade study was performed to determine the best switchgear options for the OTEC system, both on the platform and onshore. For the type of breakers needed, there are two commercially available choices: Air Insulated Switchgear (AIS) and Gas Insulated Switchgear (GIS). For the AIS option, air is used as a natural insulator between conductors and a vacuum tube that contains the separation contact for each phase. AIS are generally low cost and more readily available than GIS, but there are several drawbacks. Air insulation requires large conductor spacing to prevent flash over between the phases. This requires a larger footprint for equivalent size switchgear. An alternative is GIS, which uses an inert gas (usually sulfur-hexafluoride) for insulation between the conductors. The gas also immerses the separation contacts eliminating any potential for arcing during operation. GIS is advantageous over AIS for its smaller footprint and shorter life-cycle cost, but it is undesirable from its higher capital cost. For the pilot plant design, the tradeoff was made to utilize GIS for switchgear rated for 15 kV and higher and AIS for the 5 kV switchgear. Figure 3-171 shows a cutaway of an ABB GIS switchgear. Figure 3-172 shows a cutaway of an Areva AIS switchgear

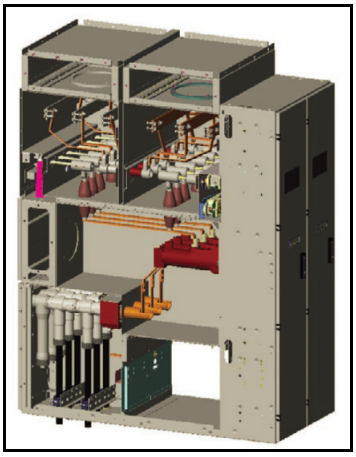


Figure 3-171. GIS cut away (from ABB)

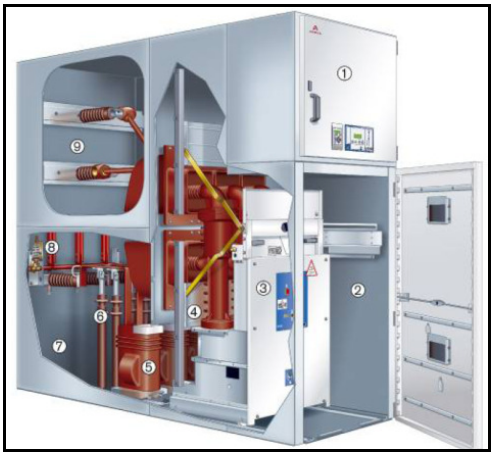


Figure 3-172. AIS cut away (from Areva T&D)

The full list of switchgear, with top level specifications, for the platform substation is shown in Table 3-59. The list of specifications is currently preliminary for the Pre-FEED design.

Table 3-59. Switchgear for the platform substation

Switchgear	Quantity	Type	Standard	Nominal Current (A)	Fault Current (kA)	Utilization
5 kV	4	AIS	NEMA	600	20	Pumps/Distribution
15 kV	7	GIS	NEMA	600	20	Generator/Primary Bus
38 kV	1	GIS	NEMA	600	20	Submarine Cable

3.3.3.1.1.2 Platform Power Cabling

Several design guidelines for the cabling have been established for the platform power cables. Power cabling on the platform will comply with all ICEA (Insulated Cable Engineers Association) insulator and conductor standards. The size of the cabling will range from 600 V to 38 kV+. The insulation will typically be rated for 100% nominal voltage and in some cases 133% nominal voltage (i.e. generator cables, pump cables, etc…). A standard 125% max-current will be applied to all conductor lengths, along with an assumed .8 power factor for loading. Further requirements for the platform cabling include IEEE standard 45 for shipboard cabling. ABS will also have for cable insulation, protection, and routing such that fire and safety risks are mitigated. Further details on the cabling will be flushed out during the next design phase.

3.3.3.1.1.3 Platform Transformers

Platform transformers are used to condition the voltage coming from the OTEC generator and auxiliary power sources to a useful voltage level for platform loads and transmission to shore. Transformer technology has a very low technical risk for the OTEC pilot plant. It is very mature and has been implemented in numerous offshore applications before. Several transformers are utilized on the platform substation for power delivery. Numerous vendors exist for transformers in the size range and specifications for the pilot plant. This includes, but is not limited to, ABB, Siemens, GE Transformers, Mitsubishi, VA Transformers, Waukesha, among others. VA Transformer products were referenced during the Pre-FEED design phase because of the quality of their readily available technical information. A comprehensive vendor search will occur during FEED. Figure 3-173 shows an oil filled transformer like that required for the OTEC pilot plant.



Figure 3-173. Oil Filled Megawatt Transformer (from VA Transformer)

The key parameters for sizing a transformer is the turn's ratio, rated power, fill type, and winding configuration. The turn's ratio and rated power are driven by the requirements of the generator and various loads. The fill type is driven by size, weight, safety, and environmental considerations. Winding configuration is driven by maintaining system reliability through isolating the various segments of the power systems from ground faults. The choice between a Delta vs. Wye winding configuration is dependent on the source, the load, and possible fault scenarios. For the baseline of the Pre-FEED design, all transformers are Delta-Wye from the source to load side respectively. This minimizes zero sequence current faults from passing through the transformer to the load or vice-versa. The voltage rating of the primary and secondary side of the transformer will match the bus voltages of the platform architecture. The power MVA rating for the transformers is sized such that the rating is 125% of the maximum expected throughput power with a 0.8 power factor assumed. This is consistent with the industry standard of minimum 150% sizing from peak MW load to MVA rated capacity. Finally, the fill

type whether dry vs. oil immersed must be evaluated. Dry type transformers have the advantage of being lighter weight and cheaper, but require a larger footprint for heat dissipation and are generally not practical for large sizes. Likewise, oil immersed have smaller footprint and higher efficiency but come at greater cost. There are also safety and environmental risks that need to be considered for oil-filled transformers. The potential for fire is greater as is the chance of oil leakage into the seawater. However given the fact that oil-filled transformers of large MVA size are currently installed on currently operational offshore Oil & Gas platforms, these risks have been successfully mitigated.

For the selection of transformers, consideration must also be given for the future upgrade to 10 MW-net-average. For the Pre-FEED design, it was decided that the transformer for the transmission segment will be initially sized for the future 10 MW upgrade. This decision was reached by looking at the cost and footprint impact of initially sizing of the 5 MW pilot plant and adding a second transformer during the upgrade. To optimize the resource utilization for the transformer, a fan cooling system will initially be left off of the transformer. This will derate the transformer from the upgrade capacity to the initial capacity. For the platform load distribution transformers, they will be sized for the full future platform load and allocate space for an equivalent transformer to be installed in parallel for the upgrade to a 10 MW system. The full list of platform transformers is given in Table 3-60. The implementation of the transformers on the platform can be seen in Figure A3.3.3-4, -5, -6, and -8 of the Power Delivery Appendix 3.3-36.

Table 3-60. List of Transformers on the Platform

Power Rating (MVA)	Quantity	Primary Side (kV)	Secondary Side (kV)	Windings	Fill Type	Load
20	1	13.8	34.5	Delta-Wye	Oil	Transmission
5	1	13.8	4.16	Delta-Wye	Dry	Seawater Pumps/Platform Distribution
5	2	13.8	.48	Delta-Wye	Dry	Test Load Bank
.5	2	4.16	.48	Delta-Wye	Dry	Low Voltage Loads
.1	1	.48	.12	Delta-Wye	Dry	Low Voltage Loads

3.3.3.1.1.4 Platform Control Cabling

Several design guidelines for the cabling have been established for the platform power cables. The control cabling will support control loads varying from a few volts up to 125 V DC for the power system control equipment. Cabling will comply with ICEA standards. Current capacity of the cabling will be rated for at least 150% of the max current rating. The full specifications of the control cabling will be flushed during the FEED phase of the project.

3.3.3.1.1.5 Platform SCADA

The supervisory control and data acquisition (SCADA) system on the platform manages all of the controls and instrumentation of the power delivery segment. On the platform substation, SCADA is responsible for collecting voltage, current, frequency, and other vital signals from equipment installed on the platform. Control features of the SCADA system include the adjustment of protective relays, transformer load tap changers, and environmental controls, among other features. The SCADA interfaces directly with the platform integrated instrumentation & control system (covered in 3.3.4).

One of the main functions of the SCADA system is to supervise the protective relays used for controlling the switchgear within the substation. Digital relays measure voltage and current on a bus for abnormal conditions. If an abnormal condition is detected a trip signal can be sent to the various switchgear to protect the system from an unsafe fault condition. For the transmission segment, impedance relays will be utilized. The impedance relays will check for changes in the cable impedance as a detection of a fault occurring and locate the fault in the designated zone. Relays on the platform substation and onshore isolate each segment from cable faults.

Figure 3-174 shows the implementation of impedance relaying the transmission system protection. For the larger transformers, differential relay protection will be utilized. For the Pre-FEED phase, high-level relaying philosophies have been adopted.

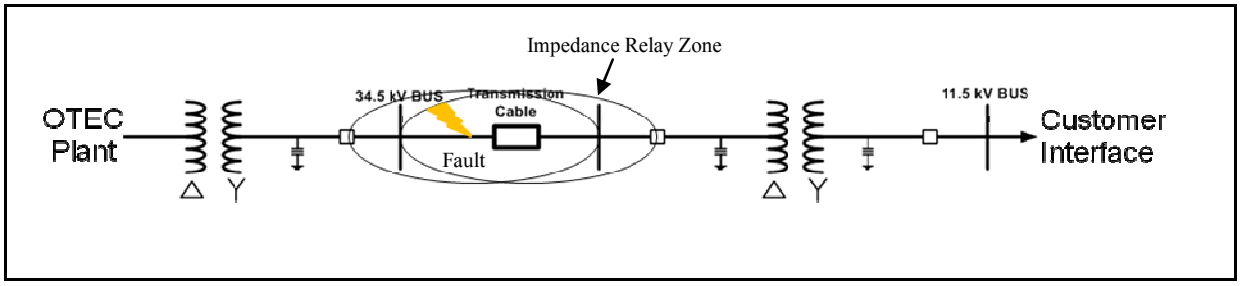


Figure 3-174. Impedance relaying for the transmission cable

3.3.3.1.1.6 Platform Battery Arrays

Several ground rules for the low risk and mature battery system have been established. Space & weight allowances have been made, both within the platform substation room and control center, for a standard 125 V DC battery array. The standard battery technology utilized in substation applications is lead-acid and is thus the baseline battery for the Pre-FEED design phase. The battery array will power the digital relays, switchgear consoles, and emergency communication systems. Figures A3.3.3-11 and -13 in the Power Delivery Appendix 3.3-36 show the physical allocation of the battery system for the substation and control center.

3.3.3.1.1.7 Test Load Bank

For the pilot plant, a test load bank will be required on the platform to fully test the power generation segment and platform substation prior to interconnection with the customer grid. The test load bank will be installed on the platform only during the two year pilot phase. It will be located in the space allocated for the 2nd turbine-generator set. The test load will replicate, as accurately as possible, the dynamic characteristics of the OTEC plant connected to their distribution network. To emulate this, a resistive/reactive load bank will be used. The resistive portion of the load bank is used to dissipate the power generated as heat. The reactive portion of the load bank is used to store energy in a magnetic field. The reactive component allows the load bank to emulate the natural lagging power factor of electric grids. The load bank is fully controllable with 25 kW/18.75 kVAR (kilovolt-ampere reactive) load steps. This allows for a wide variety of load test cases to be applied to the turbine-generator to test the performance. For the Pre-FEED design, two 4 MW/5 MVA load banks will be used in parallel. Two are utilized to test the full capacity of the OTEC turbine-generator. The load bank buses are rated for 480 V L-L (voltage line to line) each. Their voltage is limited to 480 V to allow for them to be packaged in a standard ISO (International Standards Organization) shipping container for ease of transport. There are a handful of vendors that can provide test load banks in the size required for the pilot plant. An Avtron load bank was referenced for the Pre-FEED design. Figure 3-175 shows the Avtron load bank referenced for the Pre-FEED design.



Figure 3-175. Test Load Bank for Pilot Plant (from Avtron)

Overall, the load bank has relatively low technical risks. One challenge is with protecting the power delivery segment from faults that occur within the load bank. The maximum current each load bank can draw is over 6000 amps. The maximum fault current is over 86 kA. Most commercially available switchgear is rated for 60 kA. Custom switchgear has been previously built for fault currents up to 100 kA, but is more expensive and challenging to procure. For the Pre-FEED design extremely inverse fuses are attached to the input of each load bank.

3.3.3.1.1.8 Startup Generator

A startup diesel generator is required to startup power generation system that includes the seawater pumps and platform auxiliaries required to start up the power cycle. The generator provides power to the seawater pumps until the OTEC thermal cycle reaches its steady state operation. Once this occurs, the diesel generator is operated in parallel with the OTEC turbo generator and begins a graceful shutdown. The capacity of the startup generator is rated for 2.5 MW/3.1 MVA. It is sized for 125% of maximum load power and has sufficient motor starting capacity to start the pumps. The terminal voltage is 13.8 kV L-L. The startup generator ties into the main generator bus. The current concept of operation allows for a single generator of 2.5 MW to be installed for both the 5 MW pilot phase and the future upgrade to 10 MW. This is because the startup generator is needed only to start only a single set of seawater pumps at a time and bring one turbine-generator online. After the first turbine generator is online, the startup generator can be shutdown. There are no significant technical risks associated with the startup generator. Maintenance and fuel storage logistics still need to be worked during later design stages. Multiple vendors can provide a startup generator for the pilot plant. Caterpillar offshore diesel generators were referenced for the Pre-FEED design.

3.3.3.1.1.9 Auxiliary Generator

An auxiliary generator is required to power the OTEC plant during the initial platform integration and test, to manufacture the cold water pipe, and to power the platform during periods of extended offline maintenance. The auxiliary generator will be utilized when it is impractical to run the larger startup generator for long periods. The generator is sized for 0.5 MVA, which is 125% of the auxiliary load (minus seawater and ammonia pumps). The generator terminal voltage is 480 V and interconnects at the low voltage auxiliary bus. There are no significant technical risks associated with the startup generator. Maintenance and fuel storage logistics still need to be worked out, similar to the startup generator. Multiple vendors can provide an auxiliary generator for the pilot plant. Caterpillar offshore diesel generators were referenced for the Pre-FEED design.

3.3.3.1.2 Power Transmission Subsystem

The power transmission subsystem encompasses all of the transmission hardware from the terminals leaving the platform substation to the terminals entering the onshore substation. It is the only subsystem of the OTEC plant that traverses the platform, subsea, and onshore. This includes the submarine cable, land cable, and associated support hardware. The power transmission subsystem has the highest technical risk for the power delivery segment. The submarine cable is a high risk item for the power transmission because no such cable has been currently installed. The technical challenges with the submarine cable will be further discussed in section 3.3.3.1.2.2 submarine cable. The key requirements for the power transmission system are given in Table 3-61.

Table 3-61. Key Requirements for Power Transmission Subsystem

Requirement	Source	Rationale
The transmission system shall deliver a maximum of 12.7 MW-net to shore for the customer.	Top Level	Driven by top level requirements for future upgrade to 10 MW-ave-net. Net power is measured on-shore.
Submarine cable shall operate efficiently in a temperature range of 28 °C to 4 °C ambient seawater temperature.	Derived	Cable manufacturer must be aware of thermocline on riser and seafloor portion to determine how cable performance is affected.
The submarine cable riser section shall have a transmission voltage rated for 34.5 kV (To Be Reviewed).	Derived	Rating based off current baseline for power delivery subsystem. Requirements driven by ANSI/ICEA specification and dynamic cable technology. Voltage sized for largest currently available dynamic cable.
Submarine cable shall operate efficiently in an environment with a seafloor thermal resistivity of 1.2 Km/W TBR.	Derived	Ground resistivity required to calculate cable efficiency and design appropriately. Precise resistance number TBR.
Submarine cable shall be buried a depth of 1 meter when the cable is in water depth of less than 100 m TBR.	Derived	Protect cable from bottom fishing, anchoring, and other human activities that could damage the cable.
The submarine cable shall be armored to minimize potential for damage from contact w/ sharp outcroppings on seafloor.	Derived	In areas where there are rock outcroppings and/or coral, cable is especially vulnerable due to abrasion. In these areas, armoring is normally used.

3.3.3.1.2.1 Platform Termination

The platform termination handles the interface of the submarine cable to the platform. It incorporates the attachment on the topsides, routing through the platform hull, and hang off point at the base of the platform. The platform termination will consist of either an I-tube or J-tube for attaching the cable to the hull structure. The termination will maintain the minimum bend radius of the cable through the substation interface to the hang-off point. This component is a low technical risk and high availability. This type of termination is common for floating offshore platforms and while the cable may be unique, the mechanical properties are similar to cables currently installed in offshore oil & gas platforms.

3.3.3.1.2.2 Submarine Cable

The submarine cable carries the greatest risk and most expensive component of the power delivery segment. More than 80% of the total cost of the power delivery section is directly related to the submarine cable. The design of the submarine cable is leveraged heavily from existing offshore power cable technology. In particular, power cores for offshore wind farms were extensively researched for their commonality with the OTEC pilot plant, in terms of relative power rating and electrical requirements. While this provides a relative comparison for the electrical parameters, there are several mechanical challenges related to the cable that need to be addressed. The first is the seafloor depth. The current site location for the OTEC plant has the submarine cable touching down at approximately 1000 meter water depth. This depth will exert up to 100 atm of pressure on the outer wall of the cable. The internal core of the cables must survive this stress such that no damage occurs to the conductor, insulator, or conductor screen. The dynamic stress on the cable is another technical challenge that must be overcome. The riser portion of the cable that descends from the platform to the seafloor will experience dynamic forces exerted on it from the motions of the platform and subsea currents. The mechanical & deployment challenges are addressed in the subsequent sections 3.3.3.1.2.2.1, 2, and 3.

The top-level specifications for the submarine cable were developed after a multi-year iterative study of the submarine cable electrical and mechanical properties, literature review, and vendor/expert engagement. The specifications selected are focused on utilizing existing cable designs and strengthening the outer cores to make the cable suitable for the OTEC pilot plant. Analytical design work for the submarine cable is located in Appendix 3.3-36. The summarized top-level specifications are given in Table 3-62.

Table 3-62. Top-Level Specifications for the Submarine Cable

Parameter	Rated Value	Standard Variability	Unit
Onshore Power	20	5-7.5	MVA
Terminal Voltage L-L	34.5	32.3-34.5	kV
Current @ 5 MW	104	87-266	A
Efficiency @ 5 MW-net	97	96-98	%
Voltage Regulation @ 5 MW-net	3.5	2-4%	%
Frequency	60	+/- .1	Hz
Power Factor	0.8	0.8-.95	-
Cable Length	35	-	km
Conductor	Copper	-	-
Insulation	XLPE (cross linked polyethylene)	-	-
Conductor Screen	.5 mm Copper	-	-
Armor Type	Helical Double Layer Steel 4 mm thick	-	-

Numerous submarine cable vendors have been engaged regarding the submarine power cable. From the initial list of 12+ vendors/manufacturers, 4 have been identified as being able to supply an OTEC pilot plant size cable. The list of companies is ABB, Nexans, Prysmian, and JDR cables. For the Pre-FEED cable, JDR Cables were referenced for the design. The ultimate selection of the vendor to build the cable must also include, in addition to technical specifications; lead time, vessel logistics, installation cost, and R&D capacity. The key technical challenge for the submarine cable is deploying a dynamic cable, at the required power, to the depth requirement of the plant. More vendor interaction will be required during the next phase of the design. It is recommended that an external cable study is funded to review the OTEC submarine cable requirements and develop a suitable custom cable for the application. Figure 3-176 shows the cross section of a candidate cable referenced for Pre-FEED.

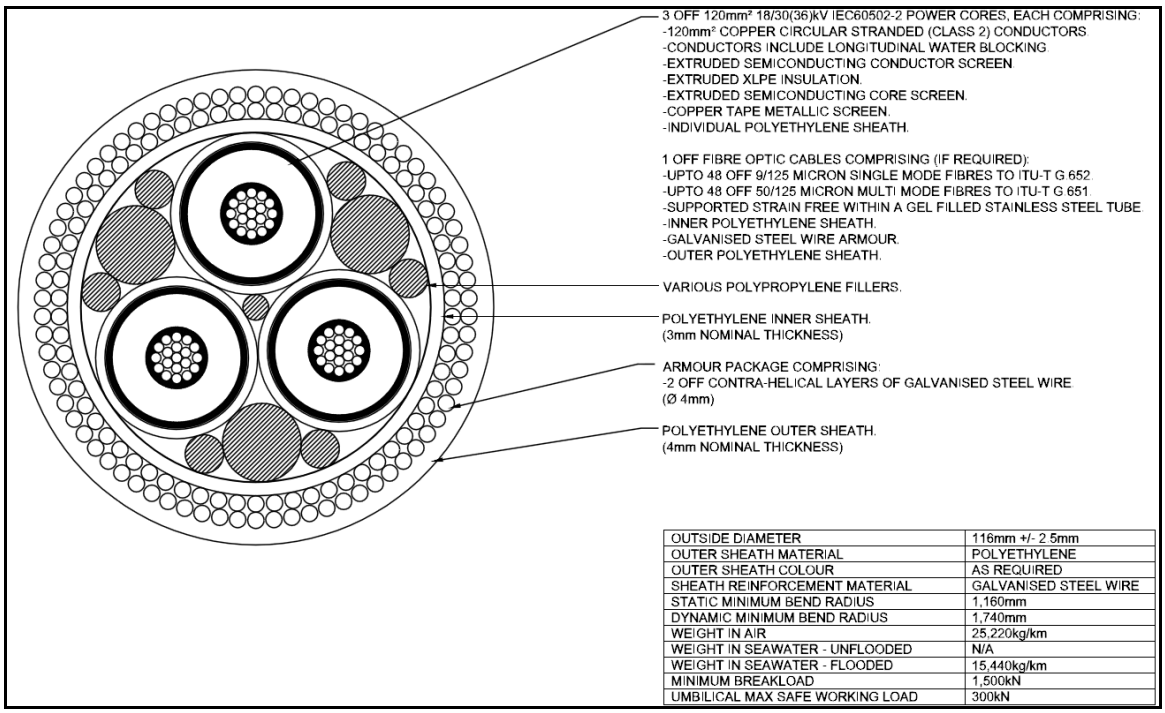


Figure 3-176. Submarine Cable Cross Section (from JDR Cables)

3.3.3.1.2.2.1 Subsea Cable Suspended

The subsea cable suspension encompasses the subsea buoys required to suspend the cable and minimize motions from on the riser portion of the cable. The riser portion of the cable is a significant technical challenge. Mechanical motions on the seafloor induced by the platform watch circle need to be reduced to prevent wear and premature failure of the cable protective armoring. To help accommodate this requirement, a decoupling mechanism is installed to produce what is called in the offshore industry a lazy S to decouple the riser portion from the platform, as shown in Figure 3-177. The subsea buoy applied to the riser acts as buffer between the platform motions and the seafloor termination. The buoy remains somewhat stationary

reducing the fatigue of the cable to the portion between the buoy and the platform but with significantly reduced loads.

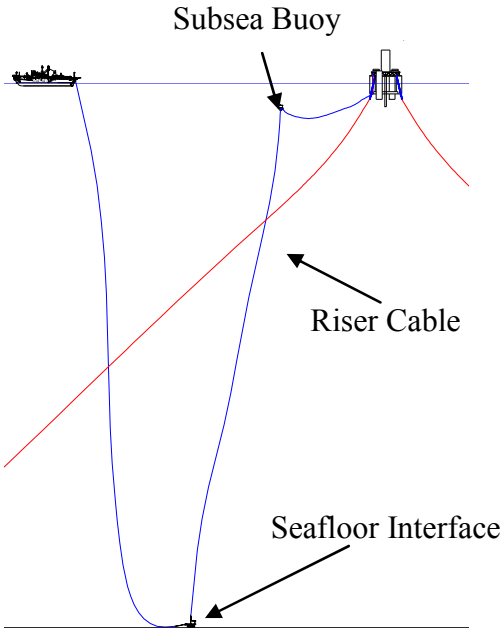


Figure 3-177. Cable Riser and Seafloor Termination

The riser cable for the OTEC pilot plant is a unique challenge. At the time of this report, there are no known dynamic cables installed that have comparable specifications for voltage, power, depth, and dynamic motions. For offshore Oil & Gas, deepwater dynamic cables have been installed, but generally at lower voltage and power ratings. Offshore wind has generally the same voltage, but lower power and shallow operating depth. Likewise, large power submarine cables tend to be static and do not have a flexing riser portion. While no major technical challenges have been indentified that would impede the development of a power cable that meets the OTEC specification, it still remains to be developed. Several cables are in development for offshore Oil & Gas deepwater pumping that are comparable in specifications. Most recently, Nexans certified a 24 kV dynamic cable that operates at 1500 meter water depth and is rated for 5 MW power transmission. While the ultimate implementation of these deepwater cables remains to be seen, it has shown that such cables can be designed and certified.

3.3.3.1.2.2.2 Subsea Cable Seafloor Interface

The subsea cable seafloor interface is where the cable transitions from a dynamic riser cable to a static seafloor cable. This interface consists of anchoring and structural supports needed to keep the seafloor segment of the cable stationary. While the cable itself is the same for both the segments, the interface on the seafloor is necessary to ensure the static portion of the cable does not have any movement. Given that the seafloor around the OTEC site is very rugged, any movement of the static portion can lead to significant damage to the cable outer sheath and

armoring. The seafloor interface is a fairly mature technology that is used frequently in offshore oil & gas riser cables.

3.3.3.1.2.2.3 Subsea Cable Bottom Lay

The subsea bottom cable lay covers the submarine cable system from its seafloor interface to its interface onshore. The cable itself will be the same continuous cable that is attached to the platform. The seafloor cable route will include protection for the cable to prevent damage from potential hazards as the cable approaches the shoreline. This could include protection such as protective mats, conduits, and trenching of the cable. Figure 3-178 shows an example of physical cable protection for the seafloor cable. Overall the subsea cable seafloor portion has relatively low technical risk. Further site data and geotechnical surveys will need to be conducted before the seafloor cable can be accurately designed.

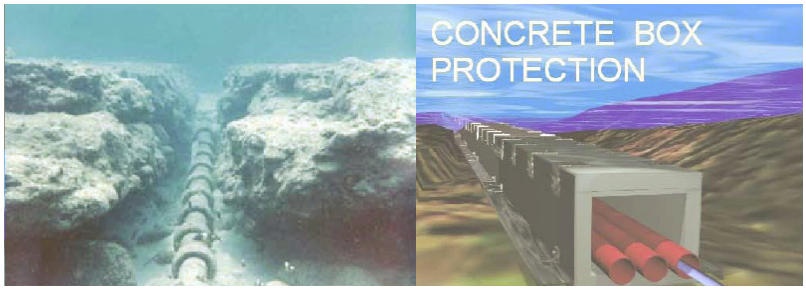


Figure 3-178. Example seafloor cable protection (from Nexans)

3.3.3.1.2.3 Shore Landing Cable Vault

The shore landing cable vault is where the transition from submarine cable to land underground cable occurs. The cable vault is located relatively close to the shore line where the submarine cable emerges from the water line. The vault will likely be required to be buried to prevent access and for aesthetics. Transitioning from the submarine cable to the land cable requires splicing the individual conductors of each cable together and applying a dielectric sheath over the splice. Interconnecting of the embedded fiber signals occurs within the vault as well. Typical dimensions for the vault fault are 1 meter-cubed. The vault will also be sealed from the external environment to prevent water penetration. There are no technical risks associated with the cable vault for the current implementation. Cable vaults are utilized throughout the world for numerous power and communication cables. Several vendors exist for providing the cable vault and splicing & installing the vault.

3.3.3.1.2.4 Land Cable

The land cable is the last leg of the power transmission subsystem. It interfaces with the cable vault and the onshore substation. The electrical specifications will be the same as the submarine cable to allow for direct connection between the two cable types. The land cable will have the same copper core, conductor screen, and cross linked polyethylene (XLPE) thickness as the submarine cable. They key difference between the land cable and the submarine cable is the lack

of armoring on the land cable. Embedded fiber optics will be used for communication between the platform and onshore substation. Figure 3-179 shows the various cable options for the land based cable.



Figure 3-179. Land based XLPE cables (from ABB)

The current baseline cable route is for the land cable to traverse from landing site 2 to the back substation on Hickam airfield through an underground cable conduit. From data received, there appears to be existing conduit from the landing site, passing near the substation that can be used to run the cable. This offers a significant cost savings from the alternative of running the cable buried directly in the ground to the substation. There are currently no technical risks associated with the land cable. The cable will comply with all local regulations and established practices for installing medium voltage power cable. There are numerous vendors for the land cable, both domestic and foreign. For the Pre-FEED design, ABB underground cables were referenced for technical information.

3.3.3.1.3 Onshore Substation Subsystem

The onshore substation incorporates all of the equipment required to interface the OTEC power plant to the customer distribution network. The proposed location for the onshore substation is adjacent to the existing Back substation on Hickam airfield. The major components of the onshore substation include a step down transformer to step down the transmission voltage to the voltage level of the distribution bus. Given the real estate constraints of the suitable sites onshore, it is recommended that the onshore substation equipment should be initially sized for the 10 MW expansion. This implementation provides significant cost and space savings for the future upgrade. The onshore substation contains virtually no technical risks as it is identical to other substations located throughout the world. Figures A3.3.3-9 and -14, in Appendix 3.3-37, show the electrical and physical layout of the onshore substation. The top level requirements for

the onshore substation are listed in Table 3-63. The followings sections review each of the major pieces of hardware.

Table 3-63. Key Requirements for the Onshore Substation

Requirement	Source	Rationale
Onshore Interface voltage shall be 11.5 kV line-line AC	Top Level	Distribution voltage for the Hickam Airfield network.
A load tap changer shall be utilized to control the voltage regulation of the submarine cable.	Derived	Compensation for voltage sagging from the submarine cable.
Gas Insulated Switchgear shall be utilized for operating voltage >5 kV	Power System Architecture Trade Study	Reduces footprint, increases reliability, reduces life cycle cost, but has a higher capital cost.

3.3.3.1.3.1 Onshore Switchgear

Two pieces of switchgear will be installed in the onshore substation. One provides protection between the submarine cable and substation transformer. The second provides protection between the substation transformer and the grid. A secondary function of the switchgear is to back up each other in the case one or the other fails to operate during a fault event. The same specification philosophy for the platform switchgear (see 3.3.3.1.1.1) is applied to the onshore switchgear. GIS switchgear rated for 38 kV is utilized for the submarine cable bus and 15 kV for the distribution bus. The utilization of GIS significantly reduces the footprint of the substation and allows for the breakers to be enclosed within the substation control house. Vendors for this equipment are identical to the vendors for the offshore variants. There are no significant technical issues associated with the onshore switchgear.

3.3.3.1.3.2 Onshore Power Cabling

The onshore cabling design is more appropriate to be developed during the FEED stage of the project, however there are several ground rules for the cabling that have been established. Power cabling onshore will comply with all ICEA insulator and conductor standards. The size of the cabling will range from 600 V to 38 kV+. The insulation will typically be rated for 100% nominal voltage and in some cases 133% nominal voltage (i.e. generator cables, pump cables, etc…). A standard 125% max-current will be applied to all conductor lengths, along with an assumed 0.8 power factor for loading.

3.3.3.1.3.3 Onshore Transformer

The onshore transformer steps down the transmission voltage to the interconnection voltage with the customer. The transformer selected for the onshore portion is similar to the platform transformer used to step-up the generator voltage for transmission (see 3.3.3.1.1.3). Key changes occur on the secondary side of the transformer. The secondary side is wound for 11.5 kV L-L. Also, a load tap changer is installed to compensate for the variability of terminal voltage out of the transmission cables. Due to the seasonal changes in power output and conditions where full power is not needed/wanted from the OTEC plant, voltage loading on the transmission cable may vary. A +/- 5% load tap changer is installed to compensate for the variation and set the secondary voltage back to within the margins of the distribution voltage. Vendors for this transformer are the same as those for the platform transformers. There are no significant technical risks associated with this transformer.

3.3.3.1.3.4 Onshore Control Cabling

Onshore control cabling design is more appropriate to be developed during the FEED stage of the project, however there are several ground rules for the cabling that have been established. The control cabling will support control loads varying from a few volts up to 125 V DC for the power system control equipment. Cabling will comply with ICEA standards. Current capacity of the cabling will be rated for at least 150% of the max current rating. The full specifications of the control cabling will be flushed during the FEED phase of the project.

3.3.3.1.3.5 Onshore SCADA

The supervisory control and data acquisition (SCADA) system onshore manages all of the controls and instrumentation of the substation. SCADA is responsible for collecting voltage, current, frequency, and other vital signals from equipment installed on the platform. Control features of the SCADA system include the adjustment of protective relays, transformer load tap changers, and environmental controls, among other features. The SCADA interfaces directly with the platform integrated instrumentation & control system (covered in 3.3.4). Likewise in section 3.3.3.1.1.5, one of the major functions of the SCADA system is to supervise the protective relays used for controlling the switchgear within the substation. For the transmission segment, impedance relays will be utilized. For the transformers, differential relay protection will be utilized.

3.3.3.1.3.6 Onshore Substation Battery

Several ground rules for the onshore substation battery system have been established. They have low technical risk and high maturity for offshore Oil & Gas and electric utility applications. Space & weight allowances have been made, both within the platform substation room and control center, for a standard 125 V DC battery array. The standard battery technology utilized in substation applications is lead-acid and is thus the baseline battery for the Pre-FEED design phase. The battery array will power the digital relays, switchgear consoles, and emergency communication systems. Figures A3.3.3-14 in the Power Delivery Appendix 3.3-36 shows the

physical allocation of the battery system for the substation and control center. The battery system will be further refined during the next phase of the contract.

3.3.3.1.4 Forward Plan

The forward plan for the entire power delivery segment is discussed in this section. For the current design effort, the Power Delivery Segment is at an early FEED level of maturity overall. All of the large hardware elements have been defined and designed to meet the current list of requirements. Further design refinement will occur during the subsequent FEED effort. For FEED, formal trade studies, analytical analysis, and firm vendor quotes will be obtained. The full list of high-level tasks for the forward plan is listed in Table 3-64.

Table 3-64. Power Delivery Segment Forward Plan

Plan	Phase
Detailed Vendor Interaction	FEED
Pilot Plant Power Stability Study	FEED
Submarine Cable Design Optimization	FEED
Full OTEC Power System Model	FEED
Pilot Plant Power Protection Study	FEED

3.3.4 Integrated Instrument and Control Segment (A4000)

The Integrated Instrumentation and Control (II&C) Segment is responsible for control of the OTEC process, and platform functions, and monitoring the instrumentation in the OTEC process, platform, and environment. This is the segment that allows for human interfacing to the other segments during normal operation. Functionally, the II&C Segment is the architecture that combines the instrumentation and controls of all the other segments. The II&C Segment consists of three elements as shown in Figure 3-180: Platform Management, Power Cycle Management, and Environmental Monitoring Management. These elements include several subsystems, each of which has one or more sets of instrumentation and controls associated with it, as described in sections 3.3.4.1 through 3.3.4.3.

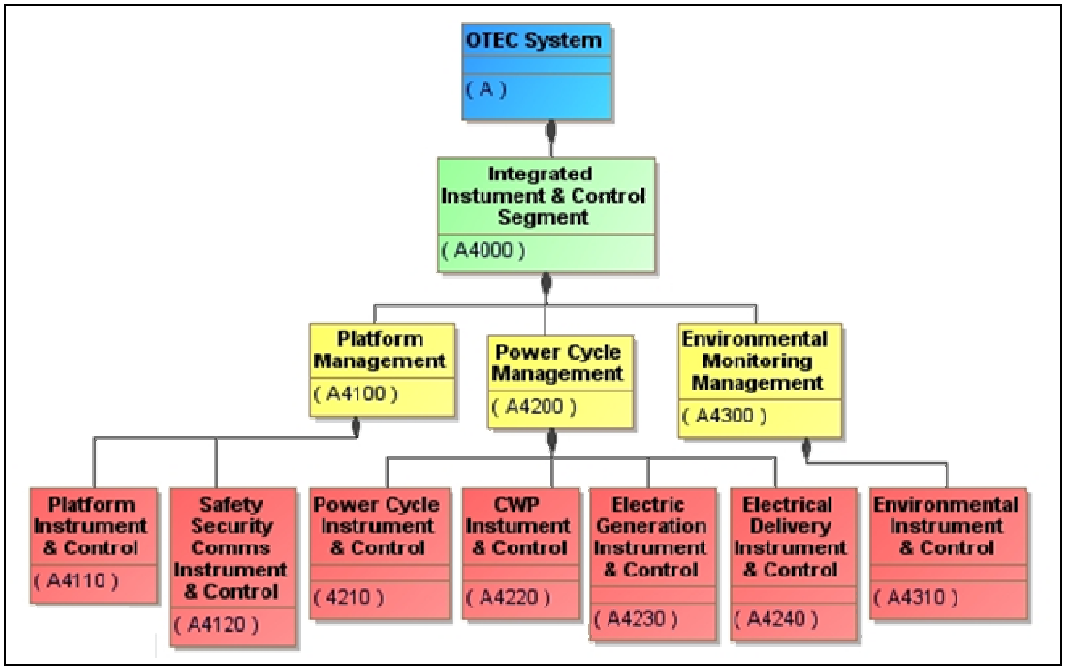


Figure 3-180. The II&C Segment Monitors and Controls All Activities On the OTEC Platform

Physically, the integrated II&C Segment consists of a single, on-platform, command and control center and the equipment in the Command and Control Center (C&CC). This equipment, referred to as the Command and Control System (C&CS), will include processors, data storage media, monitors, human interface hardware, and the software to run all functionality needed. All control effectors and instrumentation, which is physically located with their respective segments, will be connected via wired or fiber communications to the C&CS. The inputs from the instrumentation will be a combination of video, digital and analog data, while the control output will consist of digital and analog outputs. The II&C segment will be required to record all inputs and outputs.

During this contract a Failure Modes Effects Critically Analysis (FMECA) was performed for the OTEC specific hardware, software and processes (focused the OTEC Power Cycle elements). The results of this FMECA, which can be found in Appendix 3.3-38, drove a number of requirements for the II&C. Table 3-65 lists the key driving requirement that either drive the design of the II&C or other segment's hardware.

Table 3-65. Key Driving Requirements

Requirement	Source	Rationale	Impact
Onboard command and control center (C&CC).		Operators and test personnel on site during pilot test phase.	Platform Footprint, Increase in Hotel Loads
C&CC accommodates (TBR): - platform operator - power plant operator - 2 test personnel		Need access for two operators and two test personnel at a given time.	Platform Footprint, C&CC Layout/ User Interface
C&CS allows access only to authorized users	FMECA	Need to limit access to the system controls.	C&CS Software
C&CS has audible alarms and 3 (TBR) visual alert levels.	FMECA	Alert levels for critical sensors including ammonia levels, turbine speed, vibrations, etc	C&CS Hardware and Software
Keep inventory of the ammonia mass in the system.	FMECA	Will help detect ammonia leaks in system.	C&CS Software, Instrumentation Requirements
Data recording: requiring storage media change out/ backup no more frequently than 24 hours (TBR).		Need to have data storage capability that allows for at least a day of data storage.	C&CS Hardware

The network architecture for the II&C is setup to be redundant as shown in Figure 3-181. It can be seen that there are multiple user and operator access points. The Integrated Marine Management System (IMMS), described in 3.3.4.1, is located in a room with the platform operator. In a separate room or building the majority of the electrical equipment will be housed together including: the AC control panels, the mooring control panel, network equipment, and hardware specific controllers and control panels. There is an option of including the turbine and generator control panel in this area or to locate it with the hardware. The physical location of the turbine generator will not impact the network architecture. At the bottom of the figure there is the remotely located equipment. This includes cameras, as well as the remote I/O of the instrumentation and controls for the platform, power cycle, and environmental management.

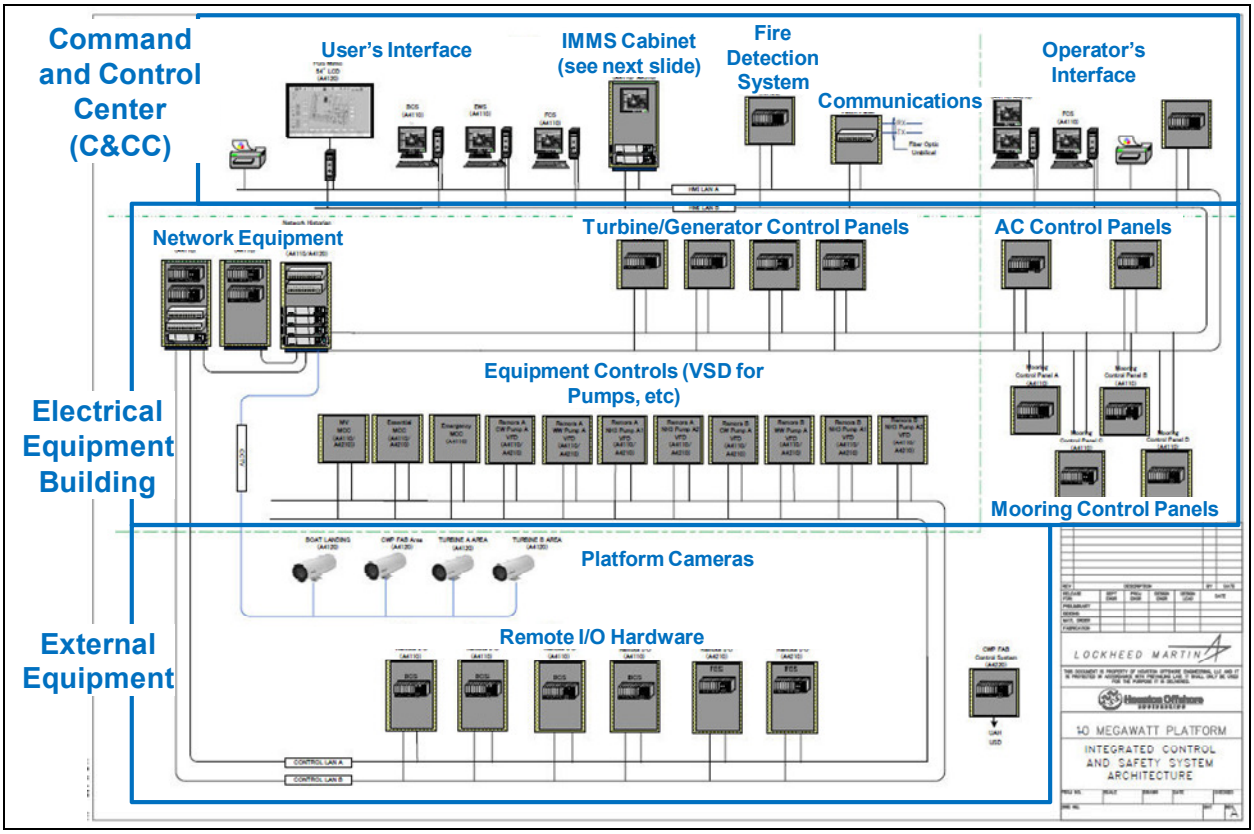


Figure 3-181. II&C Network Architecture

The current assumption is that the software for the C&CS will be purchased from a vendor that makes commercially available offshore platform management software. We will either get the software makers to modify their software to run the OTEC process and perform the environmental monitoring or we will have to write our own software for those pieces that interface with the COTS software. The other option would be to create customized software for the entire C&CS.

A preliminary set of high-level requirements were derived and need additional attention in the next phase of the program. The requirements will be needed to perform an informed trade study of the C&CC software options. This trade needs to be performed early in the program to allow for sufficient software development time if a COTS option is found to be insufficient for our needs. The path forward for the II&C segment is shown in Table 3-66.

Table 3-66. Forward Plans For II&C Segment

Plan	Phase
Power Cycle and Generation Control Architecture	Pre-FEED
Make/Buy Trade for Software for C&CC	FEED
Design C&CC including Physical Layout, Work Station Layout	FEED
Power Cycle Startup and Shutdown Sequencing	FEED
Determine Number and Types of Inputs and Outputs for the C&CC	FEED
Instrumentation and Control (I&C) Requirement Definition	FEED
What-if Scenario Cases Modeled	FEED
Design User Interface	Detailed Design
Instrumentation and Control Effectors Selection	Detailed Design
Lab Testing: C&CC Software with I&C Hardware (Mitigate Risk During Integration)	Detailed Design

3.3.4.1 Platform Management (A4100)

The Platform Management Segment includes the Platform Instrumentation and Control and the Safety, Security, Communications Instrumentation and Control.

3.3.4.1.1 Platform Instrument and Control

Platform Instrumentation and Control element includes the IMMS, mooring control, ballast control, and climate control functions. Figure 3-182 shows the details for the IMMS, which includes lightning detection, wind speed, temperature and current measurements. In addition to the IMMS the platform will have instrumentation and control related to ballasting and station keeping.

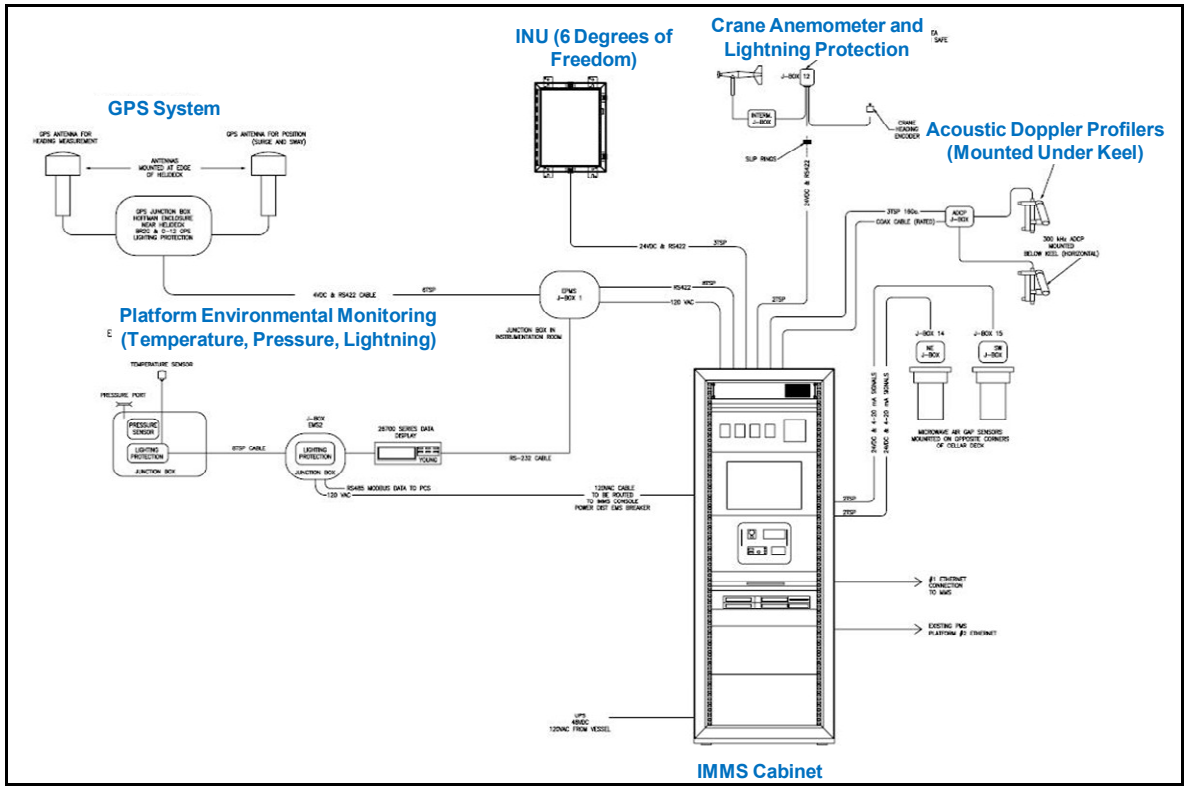


Figure 3-182. IMMS Allows For Environmental Monitoring On The Platform

Platform instrumentation and control requirement derivation was not in the scope of this contract. Requirements for this section will be derived in the next phase of this program.

3.3.4.1.2 Safety Security Communications Instrument and Control

Safety, Security, Communications Instrumentation and Control element includes physical platform security, information security, fire detection and suppression, ammonia detection, and communications. Instrumentation that will be needed as part of this section includes: ammonia sensors, smoke detectors, and video cameras. The control aspect of this element includes user access control and communications.

Safety, security, communications requirement derivation was not in the scope of this contract. Requirements for this section will be derived in the next phase of this program. Forward Plans for the Platform Management element are shown in Table 3-67.

Table 3-67. Platform Management Forward Plans

Plan	Phase
Define Preliminary Requirements to Flow Up to II&C and down to Instrumentation and Effectors Selection	Pre-FEED
Refine Requirements for II&C	FEED
Determine Number and Types of Inputs and Outputs	FEED
I&C Requirement Definition	FEED
Instrumentation and Control Effectors Selection	Detailed Design
Lab Testing: C&CC Software with I&C Hardware (Mitigate Risk During Integration)	Detailed Design

3.3.4.2 Power Cycle Management (A4200)

Power Cycle Management includes instrumentation and control for the power cycle, cold water pipe, electrical generation, and electrical delivery. Power cycle management takes advantage of an operator in the loop for the pilot plant controls. The operator will be alerted when action is needed, so the system will be designed with well defined alert and alarm levels. In addition to operated initiated control actions there are many control actions that will occur automatically with no operator intervention. Most of these automatic operations occur on the electrical generation and electrical delivery segments, as the response time need for these exceed the ability of an operator to respond. The key requirements for this element are shown in section 3.3.4.2 power cycle management (A4200).

Table 3-68. Key Power Cycle Management Requirements

Requirement	Source	Rationale	Impact
Turbine Bypass Loop	Controls Study	Allows for stability of ammonia cycle, see 3.3.4.2.1	Ammonia Piping
Control of recirculation flow from the separator to the evaporator.	Derived	Allows for more efficient operation of the power cycle.	Ammonia Piping
Control the ammonia flow from the separator to the condenser accumulation tank.	Controls Study	Need a way to control the liquid level in the demister, see 3.3.4.2.1	Ammonia Piping
Turbine governor to regulate the turbine speed to produce electricity at 60 Hz	Nominal Grid Frequency	Need to match grid frequency throughout operation.	Specification to Vender
Generator field exciter to maintain voltage	Power System Architecture Trade Study	Need to maintain nominal voltage during operation.	Specification to Vender
±5% load tap changer installed on the secondary (load) side.	Power System Architecture Trade Study	Maintain nominal voltage as load and resources vary throughout the year.	Specification to Vender

3.3.4.2.1 Power Cycle Instrument and Control

The Power Cycle Instrumentation and Control subsystem includes the instrumentation and controls for the hull subsystem, working fluid subsystem, the warm water subsystem, and the coldwater subsystem with the exception of the coldwater pipe, as described in sections 3.3.2.1.1.6, 3.3.2.1.2.5, 3.3.2.1.3.6, and 3.3.2.1.4.5 respectively. The controls for this section include the bilge pumps, ammonia feed pump, warm water pump, cold water pump, and ammonia valve positions. Instrumentation for the hull subsystem includes water detection sensors as described in 3.3.2.1.1.6. Instrumentation for the ammonia subsystem includes temperature, pressure, flow, and liquid level sensors as described in section 3.3.2.1.2.5. Instrumentation for the warm and cold water subsystem includes temperature and pressure sensors as described in sections 3.3.2.1.3.6 and 3.3.2.1.4.5 respectively. There are additional sensors that will be used as part of this subsystem, including ammonia feed pump bearing temperature and vibration, and ammonia detection sensors.

The preliminary requirements and cycle design were driven by a preliminary control studies. This study was done using Matlab's Simulink tool, a screen shot is shown in Figure 3-183. Simulink uses connected blocks to simulate a dynamic system. The model currently consists of models of each component using basic heat transfer, thermodynamic and fluids equations for the ammonia, warm and cold water subsystems. We are working on internal funding to upgrade the model to include Sinda/Fluent, a finite element tool, to perform the heat exchanger calculations. We are also working to upgrade the turbine and generator model to take into account the effect of operating off design point, and the dynamics of the electrical loading. In the current configuration the model is able to perform basic dynamics near the design points, allowing a preliminary controls study to be performed. More detailed studies will be performed as the model is updated.

The preliminary controls study had three key findings: that the ammonia cycle is controllable, the turbine needs a bypass loop, and there needs to be recirculation bypass loop. The first finding is that the ammonia cycle, as modeled, will be controllable using basic control methods. This is because the ammonia cycle has fairly slow dynamics, and with the following recommendations, the undesirable coupling will be mitigated and the unstable loops will be broken.

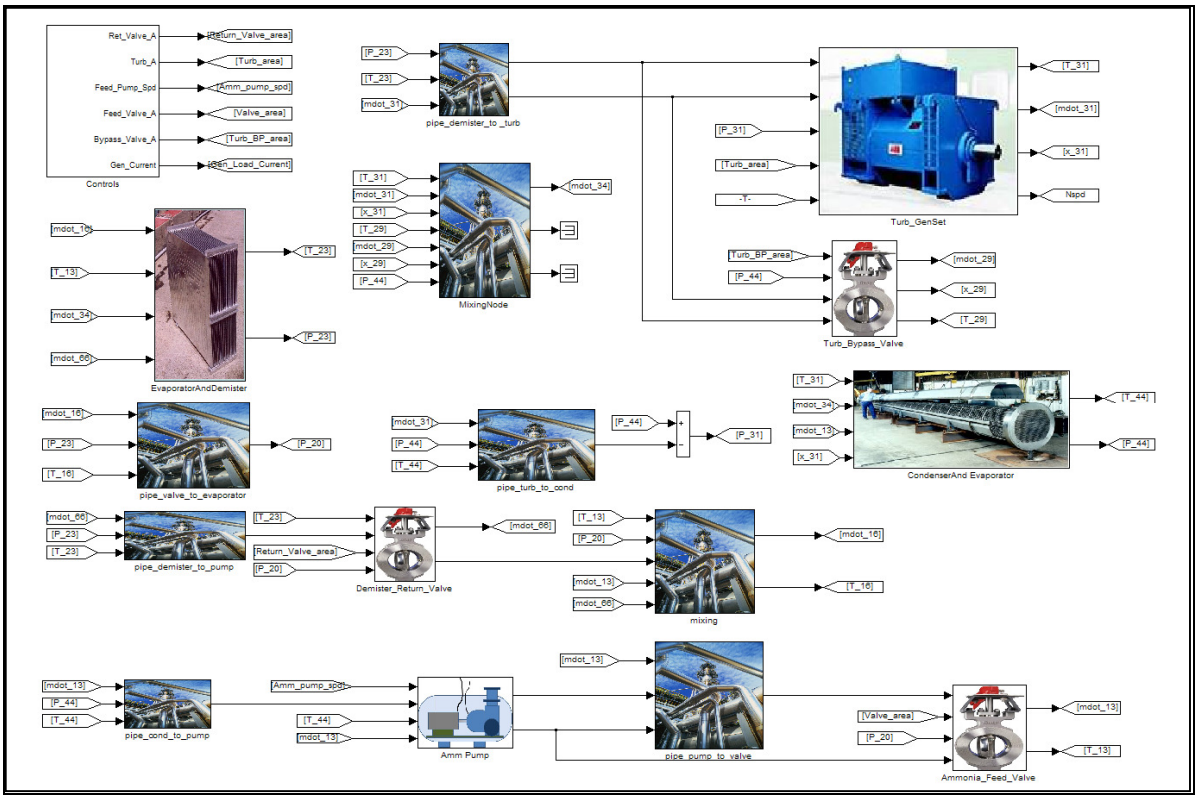


Figure 3-183. Simulink Allows For Dynamic Simulations Of the OTEC Power Process

The second finding is that the ammonia cycle requires a turbine bypass loop to be installed to make coarse adjustments in turbine speed. Turbine speed is regulated by the mass flow through the turbine. If the turbine throttles the flow to reduce speed, it causes the evaporator to build up pressure. This pressure increase throws the ammonia cycle off its set points, causing the ammonia quality to drop. If instead, a bypass valve is used to control the flow of ammonia into the turbine, the pressure in the evaporator is maintained, thus allowing the cycle to stay at its set points. A comparison of the two control methods is shown in Figure 3-184. The plot on the left shows the evaporator pressure while using the bypass valve to control the turbine speed while the plot on the right shows evaporator pressure while using the turbine throttle valve to control turbine speed. In both cases the valve is actuated at 30 seconds into the run. It can be seen that the turbine throttle valve causes a pressure increase, and settles out at the higher pressure. This higher pressure throws the OTEC plant off its ideal set points, and causes it to run less efficiently. In contrast the bypass valve causes a much smaller change in pressure, and it allows the evaporator to settle back to the same pressure it was at prior to the change in valve position. This allows the OTEC plant to work at its ideal pressure set points.

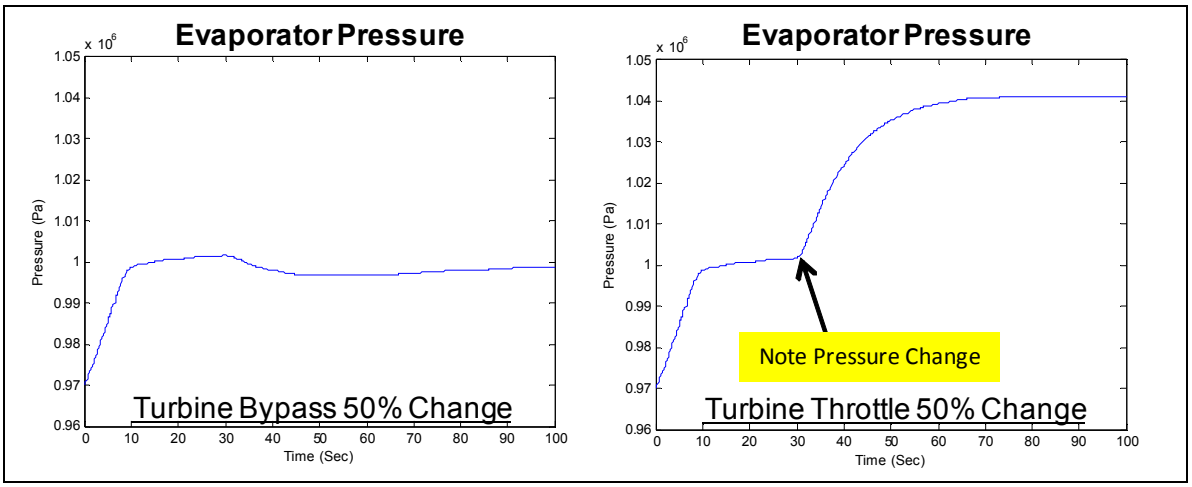


Figure 3-184. Throttling Ammonia through the Turbine Disrupts the Ammonia Cycle

The third finding is that there needs to be a recirculation bypass loop that connects the demister to the condenser accumulator. Figure 3-185 shows an evaporator's ammonia output quality as a function of ammonia flow rate through the evaporator. The graph shows heat exchanger test data for a compact plate heat exchanger. The water and ammonia inlet conditions are fixed for each test run. The three colored lines designate three different fixed water flow rates, with red being the lowest water flow rate and green being the highest water flow rate. It can be seen that the ammonia quality decreases as the ammonia flow increases. Thus, as ammonia flow rate is increased there will be more liquid exiting the evaporator. We cannot increase the flow of liquid out of the demister without increasing the flow through the evaporator. Without the recirculation bypass if the liquid level in the demister gets too high, we would have to flow more ammonia through the evaporator to remove more liquid from the demister. This increased ammonia flow through the evaporator would drop the quality of the output, thus adding even more liquid to the demister. The recirculation bypass loop is the only effective means of removing liquid buildup from the demister. The entire ammonia cycle proposed is shown in Figure 3-138. .

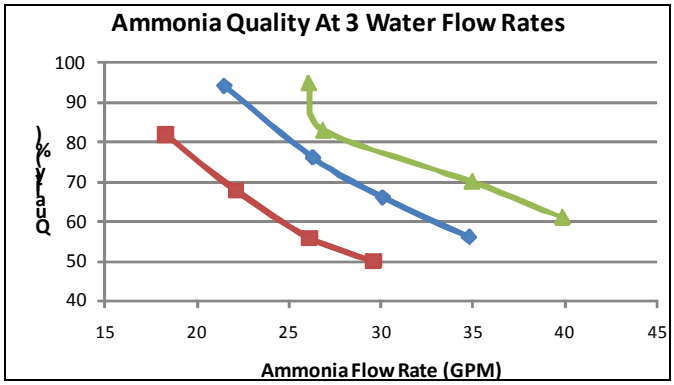


Figure 3-185. The Evaporator Is Operating Near Peak Quality Output

Requirements for this subsystem will include not only the location of sensors, described in Table 3-47. , Table 3-50 and Table 3-52. , but also the accuracy of the sensors, and performance of the control effectors. These requirements are levied onto the subsystems; for example, the requirement for liquid level sensor accuracy is levied onto the working fluid subsystem described in section 3.3.2.1.2, while the turbine speed control would be levied on the turbine subsystem described in section 3.3.2.3.

Risks for this system include imprecise system modeling, and partial requirement definition. The risk with imprecise modeling involves the simplification of the physics of the system. There is nothing currently in the model that effect changes in inlet and exit conditions on the turbine efficiency. There are no dynamics in the control effectors (i.e. pump ramp rate, valve time constants), and there is nothing in the models to show the dynamics of the generator controls or grid dynamics. This risk will be minimized by continuing to mature the system model. However, there will need to be a number of model validation tests performed to ensure the modeled components are an accurate representation of the hardware components.

The requirements for this section are only a preliminary set. It seems that the test collection requirements for the pilot plant will likely be the driver for some of the instrumentation accuracy requirements; however the test data requirements have yet to be defined. In the next phase the requirements for this section will be further derived. The additional requirement definition will help drive the design. Table 3-69 shows the future plans for the power cycle instrumentation and control.

Table 3-69. Forward Plans For Power Cycle Subsystem

Plan	Phase
Power Cycle and Generation Control Architecture	Pre-FEED
Model Updates: Turbine, Effectors Dynamics	FEED
Power Cycle Startup and Shutdown Sequencing	FEED
I&C Requirement Definition	FEED
What-if Scenario Cases Modeled	FEED
Instrumentation and Control Effectors Selection	Detailed Design
Lab Testing: C&CC Software with I&C Hardware (Mitigate Risk During Integration)	Detailed Design

3.3.4.2.2 Cold Water Pipe Instrument and Control

The coldwater pipe instrumentation and control subsystem mostly consists of instrumentation during the OTEC operation phase. It is likely that the instrumentation for this subsystem will include temperature, pressure, and strain gauges to record data for model verification purposes. The requirements for the accuracy of this instrumentation will be derived to provide the analysts with data with enough accuracy to validate their model. If a gimbal is used for the pilot plant then gimbal instrumentation and control will be added to this subsection. There have been no requirements derived for this subsystem, however, this is not a big risk, since we have margin in the number of inputs we have specified for the Integrated Instrumentation and Control Section.

Requirements for this section should be addressed in the next phase of the program. The forward plans are shown in Table 3-70.

Table 3-70. Forward Plans For Cold Water Pipe I&C

Plan	Phase
Derivation Of Preliminary Cold Water Pipe I&C Requirements	Pre-FEED
Determine Number and Types of Inputs and Outputs for the C&CC	FEED
Instrumentation and Control (I&C) Requirement Definition	FEED
Instrumentation and Control Effectors Selection	Detailed Design
Lab Testing: C&CC Software with I&C Hardware (Mitigate Risk During Integration)	Detailed Design

3.3.4.2.3 Electric Generation Instrument and Control

The electrical generation instrumentation and control subsystem consists of the instrumentation and controls for the turbine, generator, and supporting equipment. The instrumentation will include speed sensors, frequency sensors, power (voltage and current) meters, as well as lube oil temperatures, and bearing vibration sensors. Since there is a high volume of ammonia flowing through the turbine, located on the platform, there will also be ammonia sensors in the area to alert personnel to any leaks.

As described in section 3.3.2.3.1 and its subsections, the controls consist of a power flow control, health monitoring equipment and emergency controls. The power flow controls consist of a vendor supplied turbine governor and generator field exciter. This control system will likely operate as a standalone console that is connected to the C&CS to allow for data monitoring and recording as well as remote user inputs and set points. The power flow control will operate automatically, with no operator action required once the plant is started. There may be operator inputs required to create operating set points at the start of operation. The health monitoring system will monitor the health of the turbine, generator, lube oil system, and electrical connectivity. The health monitoring system will also be vendor supplied, and likely reside on the hardware with the power flow control. The health monitoring system will have inputs directly into the emergency controls as well as the C&CS. The C&CS will have alert and alarms for signals coming from the health monitoring system. These alerts will include early indication of failures or maintenance items. The emergency controls will take the inputs from the health monitoring system and determine if action is required to protect the equipment or personnel. These emergency actions will take place independent of the operator. The operator will be able to initiate any action that the emergency controller would if he see a problem in the health monitoring data.

The interface between the OTEC II&C and the turbine and generator controls will be defined in the next phase of the project. This definition will help with requirement derivation for the electrical generation I&C as well as the power cycle I&C. The forward plans are shown in Table 3-71.

Table 3-71. Forward Plans For Electric Generation I&C

Plan	Phase
Determine Preliminary Requirements for Emergency Controller	Pre-FEED
Document Interface Between C&CS, Emergency Controller, and Health Monitoring Equipment	Pre-FEED
Refine Requirements	FEED
Determine Number and Types of Inputs and Outputs to C&CS	FEED
Hardware Selection	Detailed Design
Lab Testing: C&CC Software with Hardware	Detailed Design
Lab Testing: Emergency Controls Reacting to Faults	Detailed Design

3.3.4.2.4 Electric Delivery Instrument and Control

The electric delivery I&C focuses primarily around equipment protection. Most of the controls are automated, requiring no operator intervention. The preliminary design includes a platform and on shore SCADA, as discussed in sections 3.3.3.1.1.5 and 3.3.3.1.3.5, both of which interface directly with the C&CS. The interface between the SCADA and IMMS systems was not part of the scope for this contract. In the next design phase the interface will need to be defined. The forward plans are shown in Table 3-72.

Table 3-72. Forward Plans For Electric Delivery I&C

Plan	Phase
Preliminary Requirement Definition	Pre-FEED
Interface Definition	Pre-FEED
Refine Requirements	FEED
Determine Number and Types of Inputs and Outputs to C&CS	FEED
Hardware Selection	Detailed Design
Lab Testing: C&CC Software with I&C Hardware (Mitigate Risk During Integration)	Detailed Design
Lab Testing: SCADA Reacting to Faults	Detailed Design

3.3.4.3 Environmental Monitoring Management (A4300)

Environmental Monitoring Management is the element responsible for the instrumentation and control related to environmental monitoring done by the II&C segment. This is the least well defined section of the II&C segment. The current thought is that a majority, if not all, of the environmental monitoring will be done separate from the II&C, such as taking samples and sending them to the lab for analysis. However, there may be some amount of instrumentation that will be monitored and recorded as part of the II&C. This may include discharge water temperature and other data related to the discharge plume. In the next phase of the program there

will be requirements definition that includes determining what testing and monitoring will be done as part of the II&C and what will be done manually. The forward plans are shown in Table 3-73.

Table 3-73. Forward Plans For Environmental Monitoring I&C

Plan	Phase
Define preliminary list of environmental monitoring to be performed and determine for each item if it will be done automatically or manually.	Pre-FEED
For automatic monitoring, determine number and types of inputs for the C&CC	FEED
For automatic monitoring, define instrumentation requirements	FEED
For manual monitoring, determine CONOPs for gathering data	FEED
Instrumentation Selection	Detailed Design
Lab Testing: C&CC Software with I&C Hardware (Mitigate Risk During Integration)	Detailed Design

3.3.5 Water Production Segment (A5000)

The first step in determining the most favorable seawater desalination processes for combining with OTEC was an extensive literature review of the technologies available. During the literature review many possible alternatives were examined and the basic fundamentals of each were noted. Based on how each alternative works, a few were selected as being suitable for commercial use and integration into an OTEC facility. The requirements in Table 3-74 were matched against each desalination process to determine which technologies were potential matches for OTEC.

Table 3-74. Water Production Key Design Requirements

Requirement	Source	Rationale	Impact
Production Capacity of 1 million gallons per day (MGD) and 50 MGD	Criteria established by technical lead	1 MGD meets several DoD tropical island base requirements while 50 MGD is pushing commercially demonstrated limits	Eliminates most desalination technologies which are not commercially available at these capacities.
Commercially demonstrated at design capacities	Criteria established by technical lead	Reduces risk	See above - limits available technologies for immediate consideration
Produce potable water within US and global water standards	World Health Organization and US EPA	Recognized international and domestic water standard agencies	Ensures compliance wherever OTEC water production is located
For distribution analysis purposes, evaluations limited to 50 km offshore	Criteria established by technical lead	Deemed logical limit for OTEC electrical generation for shore-based energy delivery	Allowed for comparative cost estimation baseline for various technologies and delivery schemes

Based on these requirements there were three processes chosen to be evaluated: multi-stage flash distillation, multiple effect distillation and reverse osmosis. Reverse osmosis was evaluated for both cold seawater and warm seawater desalination. The complete OTEC Water Production and Delivery Trade Study can be found in Appendix 3.3-39.

The evaluation procedure used is the weighted summation method of multi-criteria decision analysis. The analysis compares seven factors of the four desalination processes under consideration. Each of the factors is weighted according to its importance relative to the specific application, i.e. – a given capacity of water production in conjunction with a platform-based OTEC facility. The factors examined in this analysis are:

- Specific capital cost
- Operation and maintenance cost

- Space requirements
- Environmental considerations
- Product quality
- Cold seawater consumption
- Energy consumption

The result of the evaluation shows reverse osmosis with warm seawater is the most favorable desalination method for use with a floating platform OTEC system. Reverse osmosis with cold seawater received the second highest score followed by multiple effect distillation and multi-stage flash. The amount of cold seawater consumption is particularly damaging to the multi-stage flash and multiple effect distillation processes. The design of the particular OTEC system for this evaluation requires the cold seawater used in the desalination process be drawn away from the OTEC system prior to power production. This causes a major decrease in the power production capability of the system. The results of this evaluation are specific to the scenario outlined by the basis of design and the particular OTEC platform system being designed by Lockheed, and are not applicable to all OTEC systems. A new evaluation would need to be conducted for any variation in the alternatives considered.

While the OTEC facility is limited to an offshore platform in this study, the reverse osmosis seawater desalination system may be either on the platform or on land. If the reverse osmosis system were located on the platform, there would be need to deliver the potable water to shore. Four different possibilities for water delivery are examined including water bags, barges, tankers and pipelines. The water bags are not considered to be commercially suitable at this time. They have been used for commercial operations in the past, but fell out of favor due to problems with breakage. Each of the other delivery methods added excessive cost to the water production. The costs are not necessarily prohibitive in all cases, but in general they do not compare well with the costs of water production for a land-based system.

Table 3-75 summarizes the key results of the studies.

Table 3-75. Water Production Key Design Trades Summary

Trade Study	Results and Rationale
Water Production	Selected warm water seawater reverse osmosis (SWRO) as preferred technology for both 1 MGD and 50 MGD production. Performed a multi-criteria decision analysis (MCDA) to determine preferred technology over competing systems.
Water Delivery	Land-based SWRO system determined to be best in general due to extreme high costs of delivery systems.

Reverse Osmosis is a desalination process that forces seawater through membranes that do not allow the salts nor nearly any dissolved matter to pass. By applying a pressure differential across the membrane, the water is forced to move through it. The seawater is pre-treated to remove large debris and suspended solids. Chemicals may also be added during the pre-treatment process to fight bio-fouling within the membrane modules. After it has been pre-treated, the seawater is pumped through the membrane module. This segment of the process requires the bulk of the energy expended. There are two streams exiting the membrane module. The concentrated brine stream, which does not pass through the membrane, is rejected back to the sea. Upon its discharge the brine passes through an energy recovery system providing a significant energy savings by "recovering" a substantial portion of the energy input to create the high pressure differential required to force the water through the membrane. The desalinated permeate is sent on to a post-treatment segment for disinfection, pH adjustment and the removal of any dissolved gases. Figure 3-186 shows the components and the process flow for a reverse osmosis system. A photograph of a containerized seawater reverse osmosis (SWRO) system is shown in Figure 3-187. This setup would work well for the 1 million gallons per day (MGD) production capacity as the space requirements would not be much different between the containerized or a non-containerized system. A photograph of a large-scale SWRO system is included in Figure 3-188.

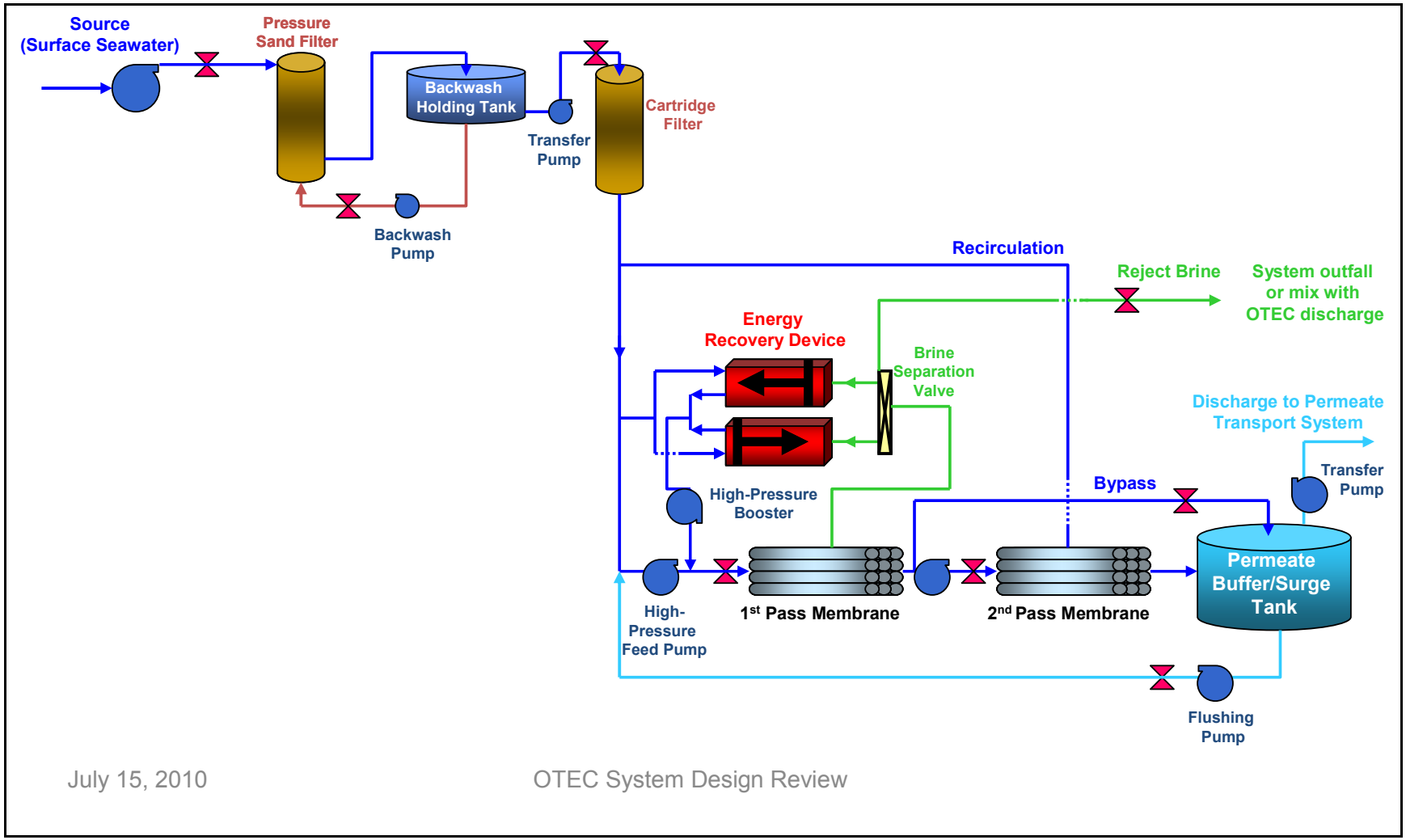


Figure 3-186. Reverse Osmosis System Functional Block Diagram



Figure 3-187. Containerized SWRO System



Figure 3-188. Large-scale SWRO System

The studies completed indicate the best alternative for seawater desalination in conjunction with a platform-based OTEC facility, such as the type considered in this particular study, to be a land-based reverse osmosis system. The future steps to incorporate such a system are listed in Table 3-76.

Table 3-76. Forward Steps

Plan	When
Decision to include water production unit into Pilot Plant	Pre-FEED
Design SWRO plant for integration into pilot platform (if included)	FEED
Develop operational plan	FEED
Develop distribution plan/design	FEED
Develop integrated instrumentation and control system	FEED

3.4 Cold Water Pipe (CWP) Fabrication System (B)

The CWP Fabrication System, consisting of the CWP Fabrication Apparatus (the composite tooling system which creates the continuous pipe), the Gripper & Handling Segment and the Environmental Enclosure Segment, is discussed in detail in *CDRL A002 Technology Development Report.* The purpose of this System is to fabricate and install on the Pilot Plant a completed 1000m long CWP of 4m diameter. Its various segments are integrated into the installed OTEC Pilot Plant platform during vessel integration and installation. Once the CWP fabrication is completed and it is permanently attached to the vessel structure, the Fabrication Apparatus, most elements of the Gripper and Handling Segment and the Environmental Enclosure are all removed and transported to a site for long term storage.

3.5 Environmental Management System (C)

The Environmental Management System (EMS) presented in this report addresses fabrication, installation, operation and decommissioning of a Navy-sponsored Ocean Thermal Energy Conversion (OTEC) Pilot Facility at a site near Pearl Harbor, Hawai‘i (hereinafter referred to as the OTEC Pilot project). Because of the complexities of environmental law and regulations, this EMS covers only the one scenario in which Navy is the lead federal agency proposing to implement an OTEC Pilot project. Other administrative scenarios are likely to require some adjustments to this approach.

The EMS describes a logical progression of environmental management in two primary segments: C1000 Permitting and planning and C2000 Operations and Monitoring (Figure 3-189). Under the current contract, Lockheed Martin has conducted the first of five EMS C1000 elements: that element (C1100 Preliminary Planning) includes a framework for the entire EMS. The remaining detail of the EMS as outlined in this report would be completed at a future date.

The purpose of an OTEC Pilot project is to develop information that will further the evolution of sustainable OTEC technology. In pursuing this goal, the OTEC Pilot project integrates environmental disciplines with engineering as an equal partner in design. This is a business model that will manage environmental issues and document the results for future use by permanent OTEC project development. Sustainable development involves meeting the needs of the present without compromising the ability of future generations to meet their own needs (UN 1987). This is a progressive role for environmental management which assembles the appropriate and relevant environmental information, achieves environmental compliance, and manages environmental impact throughout sequential technology development. Benefits are accrued when the proposal submitted to environmental regulators has already considered environmental impact and incorporated appropriate mitigation features in the fundamental design concept.

The OTEC Pilot EMS presents a pathway by which the Developer (i.e., the entity responsible for developing, testing, constructing, and operating the OTEC Pilot Plant system) and government agencies can collaborate within their respective authorities and achieve the development goal. Early planning will help identify, mitigate and resolve adverse environmental impacts during Front-End Engineering Design (FEED). Environmental integration during FEED activities can beneficially influence design when change is relatively easy and inexpensive. During operations, the OTEC Pilot EMS provides opportunity to adapt the technology in response to unforeseen environmental issues. Most importantly, the procedure provides a progressive approach linking OTEC Pilot project planning and operations to future OTEC commercialization.

3.5.1 Objectives

Table 3-77. OTEC Pilot Environmental Management System Objectives

Objective	Source	Rationale	Impact
Integrate Environmental Management	Systems Engineering Participation	Foundation for Environmental Compliance	Develop Environmental Compliance Continuity
Identify & Define EMS for Pilot Project	Project Management Prerequisites	Roadmap for Environmental Project Execution	Provide Effective Project Management
Complete Permitting & Environmental Assessment Requirements	Applicable federal & State Laws	Milestones for Environmental Compliance	Improve Efficiency Avoid Delays & Denials
Fulfill Operational Monitoring Requirements	NOAA, Scientist & Stakeholder Views	Facilitate Approval of Impact Assessment	Improve Commercialization Environmental Management
Consistent with ISO 14000 standards.	ISO	Standardized	Credible, reproducible
Comply with applicable federal, State and local environmental laws, regulations, directives and policies.	OPNAVINST 5090.1C	Compliant	Legally acceptable

3.5.2 EMS Architecture

The OTEC Pilot EMS (Figure 3-189) is conceptual in nature, providing for environmental compliance, documentation, permits, management, monitoring, adaptation and reporting. The OTEC Pilot EMS also provides critical interaction with the other OTEC Pilot project systems in support of the project goals.

The EMS segment architecture represents sequential-start work packages. In addition, the Planning and Permitting segment must be complete before starting the Operations and Monitoring segment. The Preliminary Planning element C1100 has been completed in order to prepare this report. The next steps will complete the Planning and Permitting segment, beginning with Baseline Planning, to define the specific OTEC Pilot project scope, information gap analysis, baseline data sampling plans and the initiation of baseline data collection.

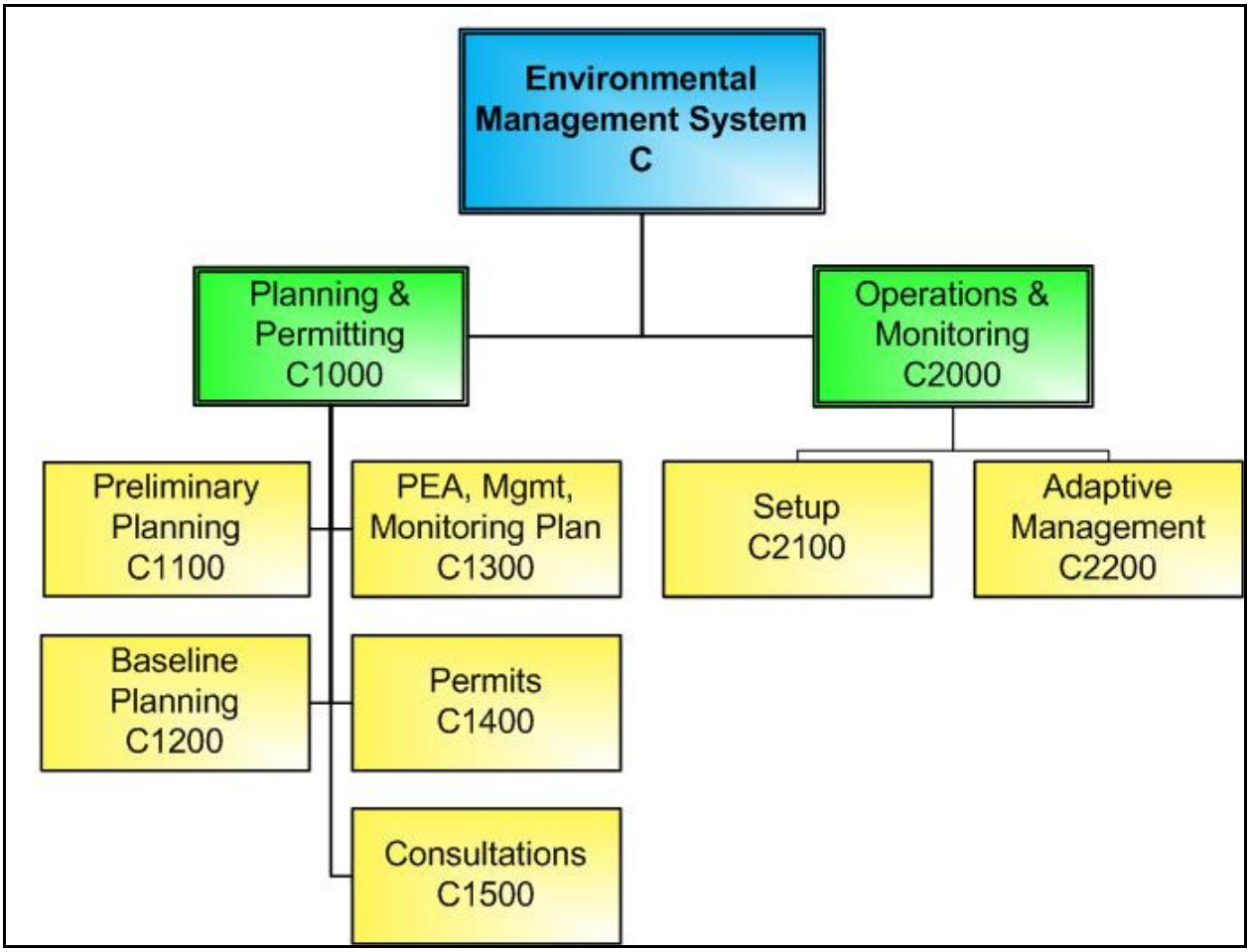


Figure 3-189. OTEC Pilot Environmental Management System Architecture

The Baseline Planning element C1200 will extend over a two-year timeframe, beginning in parallel with C1300 Proponent's Environmental Assessment, Management and Monitoring Plan (PEAMMP). It is preferable, but not necessary to complete Baseline Data Collection component (Section 0) before starting either C1400 Permits or C1500 Consultations which typically are conducted in parallel with the Navy NEPA process. The PEAMMP assembles environmental input information into one document for an efficient control turnover to the Navy. Included in this material are the first increments of baseline data collection, an impact assessment and a plan for monitoring and managing these impacts during operations. This information is Developer documentation provided to the Navy as the lead federal agency for its use in conducting Navy environmental planning for the proposed OTEC Pilot project.

The Operations and Monitoring segment is defined during Planning and Permitting. In general it will consist of a Setup phase followed by an Adaptive Management phase. The entire EMS program is marked by continuous process improvement, collaborative stakeholder involvement and documenting environmental knowledge improvement for OTEC technology.

3.5.3 Planning and Permitting Segment (C1000)

The purpose of the C1000 Planning and Permitting Segment is to provide a specific technical approach for obtaining the approvals necessary to develop, fabricate, install, and operate a Navy OTEC Pilot project. The OTEC Pilot project EMS satisfies this objective by providing a procedure that is compliant with Navy environmental policy and that needs little adjustment under new regulatory procedures that may be promulgated by NOAA and/or Department of Energy. Refer to the C1000 segment in the Planning and Permitting workflow as illustrated in Figure 3-190.

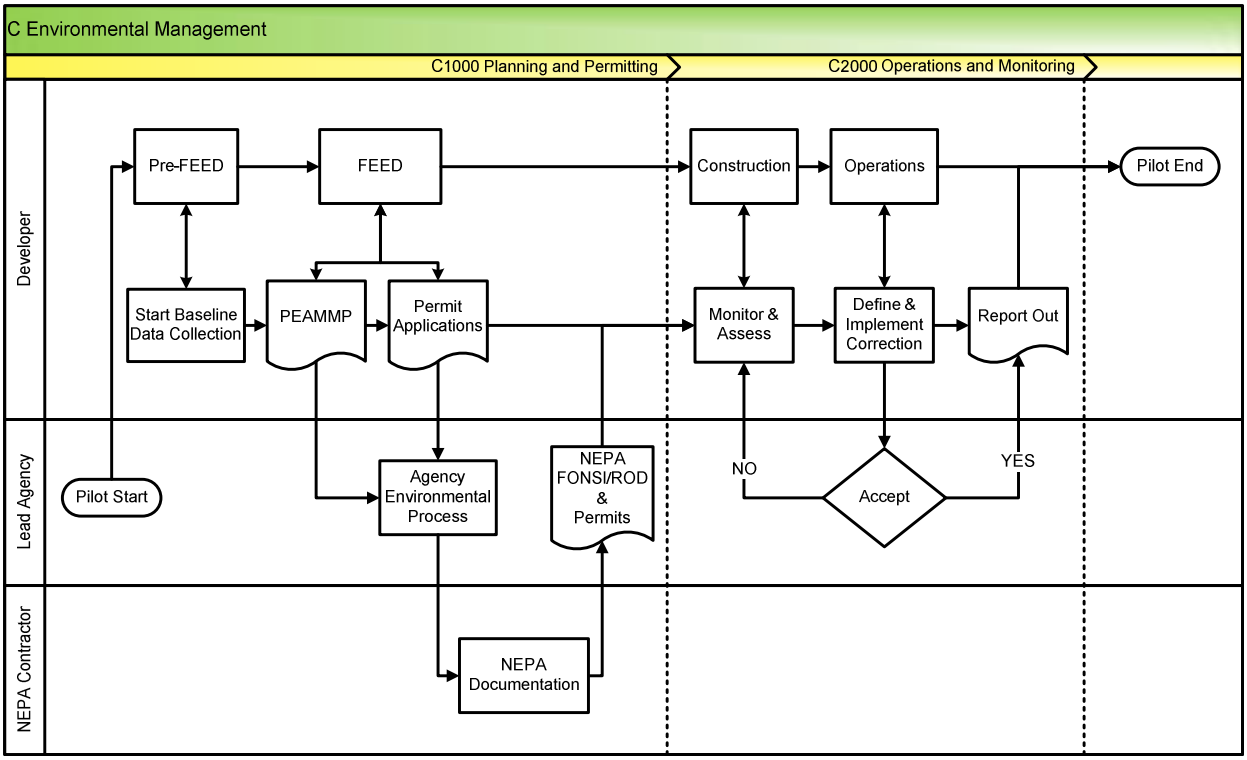


Figure 3-190. OTEC Pilot Environmental Management System Work Flow

The National Environmental Policy Act (NEPA 42 U.S.C. 4321 *et seq.*) establishes federal environmental policy applicable to all federal agencies. Implementing regulations applicable to all federal agencies are found at 40 CFR 1500-1508. Navy environmental planning regulations implementing NEPA include:

- Procedures for Implementing the National Environmental Policy Act 32 CFR 775
- Environmental Planning for Department of the Navy Actions SECNAVINST 5090.6A
- Procedures for Implementing the National Environmental Policy Act (NEPA), Chapter 5 in the Navy Environmental Readiness Program Manual OPNAVINST 5090.1C
- Navy Supplemental Environmental Planning Policy, Appendix N in the Navy Environmental Readiness Program Manual OPNAVINST 5090.1C

The Navy environmental program also includes requirements for preliminary planning to more effectively manage the cost and scheduling of document preparation. (CNO(N45) 2006) This Navy policy called the Strategic Environmental Planning Roadmap (STEP-R) provides guidance to action proponents to improve Navy environmental planning management of document cost, schedule and content. The product of the STEP-R process is a strategic environmental plan for a proposed action of definite scope. The STEP-R report typically identifies the scope of the proposed action, internal Navy and external public stakeholders, important environmental issues, and broad plans of action to address these issues. See Appendix 3.5-1 for example STEP-R information addressing a Navy OTEC Pilot Project.

Consistent with Navy regulations and policy, the OTEC Pilot EMS would develop and submit environmental baseline information to the Navy in content and form needed by Navy to comply with regulation and policy. The EMS anticipates Navy would be the lead federal agency and retain its discretional authority because of primary involvement in the outcome of the OTEC Pilot project (see 40 CFR 1501.5 and OPNAVINST 5090.1C, Appendix E). As indicated in the Navy instruction, the lead federal agency is primarily responsible for conducting the required environmental planning and, according to federal implementing regulations, assumes responsibility for the assessment of environmental impacts. If another federal agency is lead agency, Navy would support the lead agency to the extent reasonable. The lead agency is determined by all federal agencies involved in a proposed action. On occasion, two or more agencies may exercise joint lead.

In an efficient logic flow, the Planning and Permitting Segment would collect and submit baseline data, information gap analyses, and impact assessment information needed to identify relevant and appropriate management, mitigation and monitoring plans. Navy would retain the responsibility to review, consider approval, and use the information as appropriate in complying with the various federal environmental requirements.

Environmental regulations and Navy policy clearly allow Developers to provide environmental information for possible use by the lead agency in preparing an EIS (40 CFR 1506.5(a)). Federal agencies may also permit a Developer to prepare an environmental assessment. (40 CFR 1506.5(b)) Both the lead federal agency and NEPA Contractor may collaborate and use information provided by others, including proprietary technology owners. Federal regulations (40 CFR 1506.5) and the Navy environmental management policy (OPNAVINST 5090.1C 5-5.3(f)) do require avoidance of conflict of interest when selecting contractors to prepare EIS's. The objective of these regulations is obtaining unbiased environmental impact analysis during EIS preparation. In any case, the agency-published Environmental Assessment (EA) or EIS is product of the agency, having been reviewed and approved by agency personnel as an inherently governmental activity.

The Planning and Permitting segment also provides for compliance with the Ocean Thermal Energy Conversion Act (OTEC Act 42 U.S.C. §9111 *et seq.*) This law, instituted in 1980 governs the development, operation and licensing of OTEC plants and plantships. A principal intent of the OTEC Act is to "establish a legal regime which will permit and encourage the development of ocean thermal energy conversion as a commercial energy technology." (42 U.S.C. 42 U.S.C. §9101(a)(4)) An exemption from OTEC Act licensing requirements is available for an OTEC demonstration project which "...the Secretary of Energy has designated in

writing as a demonstration project for the development of alternative energy sources for the United States which is conducted by, participated in, or approved by the Department of Energy." However DOE, after consultation with NOAA would still require such demonstration projects to meet those OTECA (OTEC Act of 1980) requirements it "deems to be practicable without damaging the nature of or unduly delaying such projects." (42 U.S.C. §9126)

NOAA published OTEC regulations in 1981 and subsequently rescinded them in 1996 because no one had sought the approval governed by the regulations. The absence of regulations presents OTEC Developers with an uncertain process for designating the Navy OTEC Pilot project as a demonstration project and for any environmental requirements assigned by the Department of Energy. Regardless, the Planning and Permitting Segment provides a procedural pathway that will function under new NOAA regulations once they are promulgated.

3.5.3.1 Preliminary Planning (C1100)

This report is the result of EMS Preliminary Planning. The purpose of Preliminary Planning has been to:

- Identify and plan for compliance with environmental requirements and
- Initiate the integration of environmental management into Systems Engineering.

The focus for Preliminary Planning has been to detail the key environmental assessment work and permitting information inputs needed by Navy to prepare NEPA documentation, consultation assessments and permit applications for an OTEC Pilot Plant providing renewable energy to Joint Base Pearl Harbor – Hickam (JBPHH).

Consideration of alternative sites is beyond the scope of this report. The Navy has evaluated two other potential Navy-owned Hawai‘i sites in parallel to this work. That information would be available for future Navy NEPA documentation to support a Navy preference for one Hawaiian site over another. A comparative ecological analysis could be required to complete a NEPA impact assessment if site-selection rationale is not clearly in favor of one site over others due to economic, logistic, or engineering reasons. See also Section 3.5.5, Risks. Preliminary Planning in this report considers only environmental requirements at the Pearl Harbor site (Figure 3-191).

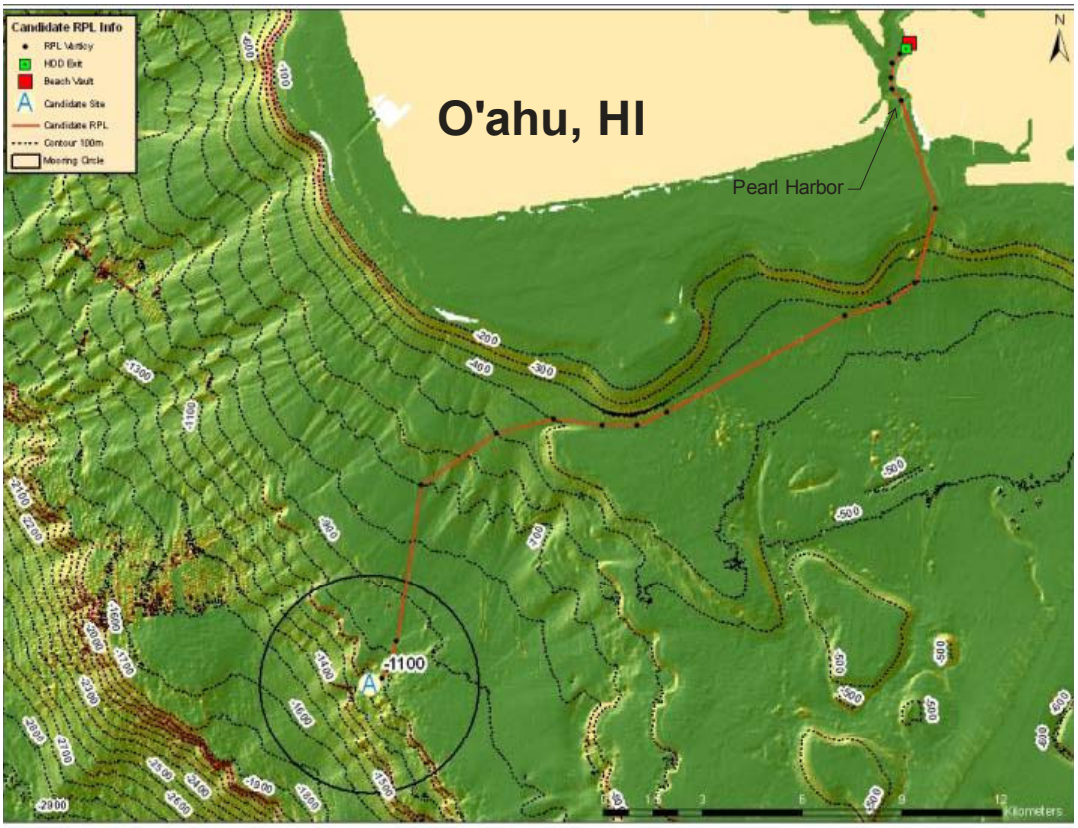


Figure 3-191. Proposed OTEC Pilot site; referred to as the Pearl Harbor or Oahu site

Systems Engineering Integration

Preliminary planning was initiated by integrating environmental planning and operations within systems engineering system for the OTEC Pilot project. During preliminary planning,

- Environmental objectives were developed as shown in Table 3-77, above; and
- Environmental compliance requirements have been reviewed and a plan developed to provide compliance as shown in Figure 3-190.
- Environmental issues were evaluated from historical literature extending back to 1970s. See also Appendix 3.5-1.

Compliance Planning

Regulatory requirements including environmental laws, regulations, Executive Orders, Defense and Navy directives were reviewed to produce a preliminary list of pertinent requirements given the proposed Oahu site for the OTEC Pilot project. The site is located approximately 8 miles southward of Barber's Point, Oahu, Hawai'i. This location places the OTEC Pilot facility within the United States Territorial Sea. Table 3-78 lists the key environmental authorizations required for a Navy proposal to construct, operate and decommission an OTEC Pilot project at the proposed Oahu site.

Table 3-79 lists key environmental documentation required by Navy during Planning and Permitting to apply for and obtain the required permits. Appendix 3.5-1 provides a detailed list of laws, regulations, policies and procedures that would require consideration during planning for a Navy OTEC Pilot project.

Table 3-78. OTEC Pilot Required Federal and State Environmental Authorizations

Federal & State Authorizations	Lead Agency	Comments
Endangered Species Act (ESA) Section 7 informal concurrence or formal Biological Opinion	United States Fish and Wildlife Service (USFWS) and NOAA Fisheries	Resource agencies provide consultation with Navy. Actions that may adversely affect listed species are subject to formal consultation.
Marine Mammal Protection Act (MMPA) authorization	NOAA	NOAA administers the MMPA moratorium on take of marine mammals
US Army Corps of Engineers (USACE) authorization	USACE	Subject to USACE jurisdictional determination re: Rivers and Harbors Act §10 and Clean Water Act §401/404 (see EPA and CWA §402 below)
Coastal Zone Management (CZM) Act Consistency Determination	Hawai‘i State	Hawai‘i CZM program review and concurrence with Navy consistency determination
OTEC Act designated “demonstration”	Department of Energy	No regulations currently in place
National Pollutant Discharge Elimination System (NPDES) Discharge & Zone of Mixing Permits	EPA Region IX	Point source discharge under the Clean Water Act (CWA) §402
Conservation District Use Permit	Hawai‘i State	Hawai‘i Administrative Rules §13-5, and subject to Navy discretion
Submerged land lease	Hawai‘i State	Dependent upon location of cable lay to shore and Navy navigational servitude

Table 3-79. OTEC Pilot Required Environmental Documentation

Federal Documentation	Lead Agency	Comments
NEPA Environmental Impact Statement	Department of Navy	EIS likely due to visibility, program cost and uncertain environmental effects
Endangered Species Act Section 7 Biological Assessment (BA)	Department of Navy	BA is submitted to USFWS and NOAA Fisheries and serves as basis for consultation under ESA
Marine Mammal Protection Act take assessment	Department of Navy	Assessment is contained within the NEPA documentation and serves as basis for applying for MMPA authorization
US Army Corps of Engineers permit application	Department of Navy	Application is submitted to the USACE for authorization under Rivers and Harbors Act and Clean Water Act. USACE is responsible for jurisdictional determinations
Coastal Zone Management Act Consistency Determination (CD)	Department of Navy	CD is submitted to the State CZM office to demonstrate consistency with enforceable state CZM policies
NPDES discharge application	Department of Navy	Application is submitted to EPA IX
Application for submerged land lease	Department of Navy	Required if Navy does not exercise the navigational servitude doctrine under the Commerce Clause of the U.S. Constitution
National Historic Preservation Act cultural, archeological and historical area of potential effect analysis and effect analysis	Department of the Navy	Effects analyses are submitted to the State of Hawai‘i
Resource Conservation and Recovery Act plans and programs	Developer and Department of the Navy	Plans and procedures are developed for implementation with EMS Pilot operations

Representatives of federal and State of Hawai‘i regulatory agencies were contacted to gather additional compliance information (Table 3-80; see Appendix 3.5-1 for a more detailed description of these meetings). During these meetings the Lockheed Martin team briefed the agency personnel on the general aspects of the LM OTEC program and sought guidance related to the permitting steps that should be anticipated and the procedural and environmental issues that will have to be resolved.

Table 3-80. Agencies Consulted

Organization	Initial Meeting Date	Location
Federal		
Army Corps of Engineers (COE)	10/14/2008	Honolulu, HI
National Marine Fisheries Service (NMFS)	12/2/2008	Honolulu, HI
United States Fish & Wildlife Service (USFWS)	12/3/2008	Honolulu, HI
Navy Region Hawai‘i	4/6/2009	Honolulu, HI
W. Pacific Regional Fisheries Mgmt. Council (WestPac)	4/9/2009	Honolulu, HI
National Oceanic & Atmospheric Administration (NOAA)	5/16/2008	Silver Spring, MD
Department of Energy (DOE)	9/14/2007	Washington, DC
Environmental Protection Agency (EPA)	10/30/2009	San Francisco, CA
U.S. Coast Guard (USCG)	12/10/2009	Honolulu, HI
State of Hawai‘i		
State Office of Planning, Energy Branch	10/13/2008	Honolulu, HI
Department of Health, Clean Water Branch (CWB)	10/15/2008	Honolulu, HI
Office of Coastal Zone Management (CZM)	10/15/2008	Honolulu, HI
Office of Coastal & Conservation Lands (OCCL)	12/2/2008	Honolulu, HI
State Division of Aquatic Resources (DAR)	4/8/2009	Honolulu, HI

3.5.3.2 Baseline Planning (C1200)

The purpose of Baseline Planning is to assemble and document specifically for the OTEC Pilot project the relevant and applicable data required for Navy to conduct its required environmental planning procedures. The Developer, in consultation with Navy technical personnel, will be responsible for this activity. This relationship allows the Developer to accurately characterize a proprietary technology for the Navy in a format required for public environmental compliance. As discussed above (Figure 3-190), this approach is permissible under federal and Navy environmental planning regulations.

Baseline Planning is initiated with the Developer completing the Systems Engineering EMS requirements definition and compiling baseline information from the technology literature, OTEC Pilot project design criteria, baseline data collection (field) and synthesized environmental impact predictions. See the work flow section labeled C1000 Planning and Permitting in Figure 3-190. Much of the baseline information and conclusions would be proprietary and documented in a limited-distribution proposal for use by the Lead Agency. Baseline Planning includes:

C1200 Baseline Planning

- C1210 Final EMS System Requirements, including a description of the proposed OTEC Pilot project proposed action
- C1220 Environmental Baseline Data
  - C1221 Literature review
  - C1222 Environmental information gap analysis based on literature review
  - C1223 Ecological resources geographically identified for the proposed project site
  - C1224 Baseline data collection objectives and testable hypotheses (sampling plan)
  - C1225 Baseline data collection (field work)

Systems engineering during Front End Engineering Design (FEED) is supported by the consideration of relevant and applicable environmental objectives that are expressed in the same quantitative fashion as other engineering factors. At sub-system levels, environmental analysis considers alternatives which would avoid or minimize adverse effects and enhance the quality of the environment. During this time the Developer has the opportunity to weigh development objectives against adverse environmental effects and to identify designs compatible with the performance objectives.

Environmental integration in FEED equitably compares environmental and design requirements. The more typical and risky environmental approach is to compare environmental requirements against design specifications and drawings. The latter approach occurs inequitably, at time when design has already considered engineering tradeoffs and made decisions. By involving environmental consideration in FEED, tradeoffs consider both engineering and environmental factors. The most equitable approach is to consider requirements against one another to identify any conflict, just as is done within engineering disciplines.

For example, a design requirement calling for unmodified and separate discharge of warm and cold water effluents might be in conflict with an environmental requirement calling for limited temperature differential between effluent and ambient waters. Available information in the literature suggests there may be a conflict. The EMS described here would provide opportunity to confirm the conflict, consider available information about the effluents and the ambient waters, and engage design team deliberation to resolve the conflict.

Environmental systems engineering requirements would avoid or reduce impacts to less-than-significant levels (

Figure 3-192). If an insignificant environmental impact is not possible, the Developer can weigh environmental impact against development objectives, documenting for the record consideration of design alternatives. The documentation would demonstrate for any unavoidable significant impact that no practicable alternative exists in the light of engineering, logistic and financial considerations.[6] Upon completion of this exercise, the Developer would have a complete

6 This is the "no practicable alternative" standard from the Clean Water Act §404(b)(1).

understanding of the potential environmental effects of the proposal; that understanding will allow it to respond effectively to agency inquiry during the NEPA documentation, permit and licensing procedures. This same process continues as needed during the remainder of the OTEC Pilot project to manage environmental impact, obtain approvals from regulatory agencies and consensus among stakeholders.

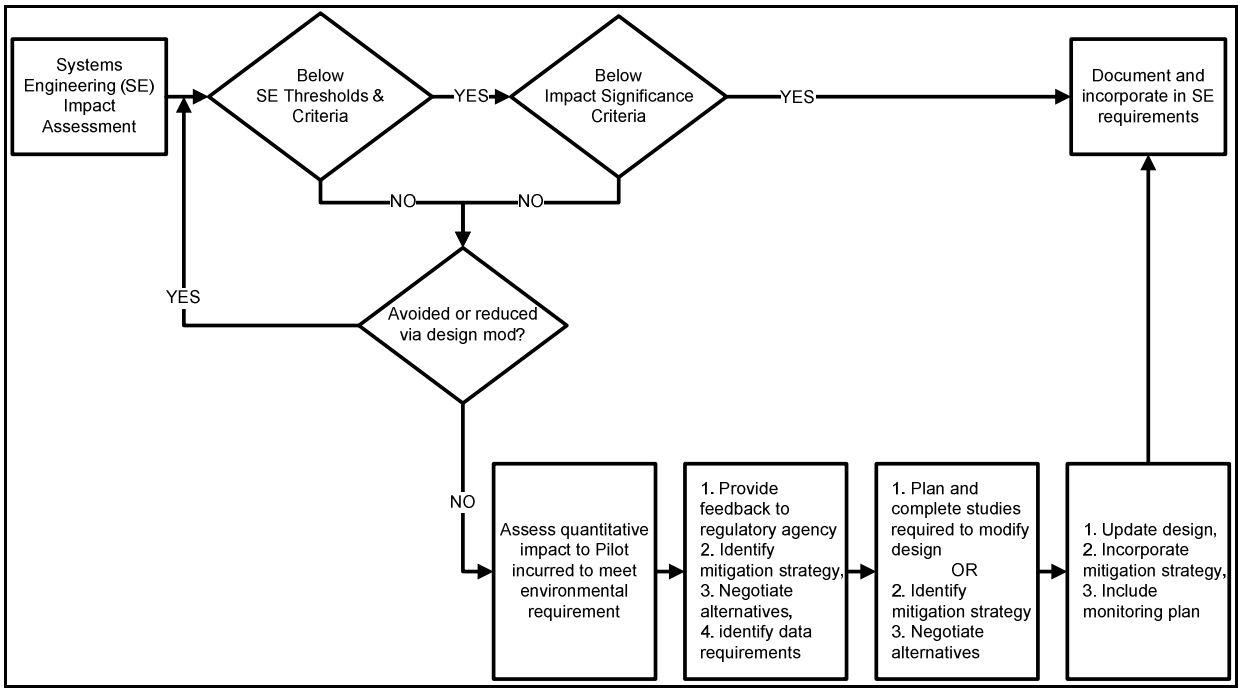


Figure 3-192. OTEC Pilot Environmental Management System Impact Management and Mitigation Procedure

Baseline data collection will focus on oceanographic characteristics in the water column where the plant intakes and discharges would occur. Site preference determinations and baseline cause and effect analysis must take place before initiating baseline data collection to identify project-specific objectives and to avoid inappropriate baseline data collection. NOAA sponsored a workshop in Hawai‘i (June 22-24, 2010) to develop guidelines for baseline and monitoring data collection requirements. Their final publications from this workshop will be the primary guidance for the development and implementation of baseline data collection and monitoring efforts. We believe that the following baseline data requirements are consistent with the consensus views expressed at this workshop.

The relatively high fluxes of water and the untested aspects of these essential OTEC systems make it crucial to establish confident baseline information that can be used to forecast potential impacts and later, monitor impacts. These collection efforts should include at least the data types outlined below and should be carried out four times a year for at least two years (See agency coordination summary in Appendix 3.5-1) prior to completion of the environmental impact documentation for the Demonstration Project. Additional, one-time studies will be necessary to

assess construction-related impacts along the seafloor power cable route, platform mooring, and sites for onshore support facilities.

Water Column Data (Two-year Baseline)

Based on a review of previously obtained data sets and on consultation with scientists familiar with environmental issues relating to OTEC deployment in Hawai‘i, we suggest the following for baseline environmental studies. The effort calls for quarterly cruises for two calendar years. Although it appears that the temporal variability in most oceanographic parameters is moderately bimodal (i.e., winter/summer) in the prospective siting area ,the finer detail offered by occupying stations four times per year (winter/spring/summer/ fall) as opposed to two times per year will lead to a fuller and more reliable understanding of overall temporal fluctuations.

In Situ Measurements

Conductivity, Temperature, Depth (CTD), fluorescence, sound amplitude and frequency distribution, and ocean current velocities (Acoustic Doppler Current Profiling) will be measured throughout the water column during the quarterly surveys. Two moored arrays would be deployed for essentially continuous measurement of these parameters before, during, and for some period after operation of the pilot plant. These data would be integrated into the results of the oceanographic surveys to provide a more complete picture of the baseline conditions than would be possible with either method alone. The sound measurements would be used both to establish baseline levels for this parameter and also to provide some identification of the marine mammal species that might pass through the area and the frequency of their occurrence. These data would also be used as they become available to consider the potential impacts of new technology.

Water Quality Parameters to be Determined

Collected water samples will be tested for levels of the following constituents:

- Salinity;
- Dissolved oxygen;
- Dissolved inorganic carbon;
- Alkalinity;
- pH;
- PCO_2;
- Inorganic nutrients (dissolved P, N, and Si species);
- Dissolved organic matter;
- Particulate C, N, P, and biogenic silica;
- Selected H High Performance Liquid Chromatography (HPLC) measurements of chlorophyll for calibration of fluorescence measurements;

- Measurements of adenosine 5'-triphosphate (ATP) to estimate living microbial biomass at all trophic levels, from large zooplankton to cyanobacteria; and
- Possibly selected measurement of trace metals such as copper, iron, mercury, and others, particularly in the vicinity of the cold-water intake location.

Plankton Studies

LM will characterize the species of plankton and micronekton found within the top 200 m of the water column and estimate their long-term average densities as a function of water depth. Plankton are passively floating, drifting, or somewhat motile organisms, primarily comprising microscopic algae, diatoms and protozoans. Micronekton are relatively small but actively swimming organisms ranging in size between plankton (< 2 cm), which drift with the currents, and larger nekton (> 10 cm), which have the ability to swim freely without being overly affected by currents (Broadeur, Seki et al. 2005). This information will be used to estimate the potential for entrainment and impingement interactions with surface water intakes and the potential for impacts on these organisms from the water discharge streams.

Seafloor Characterization

Detailed surveys of the seafloor will be required to determine the engineering requirements for mooring configurations, cable routing. Distinct but related survey work will be conducted to characterize the benthic habitats that occur in these areas. It may be possible to conduct both types of measurements while on the same survey cruises, but that will be determined at a later date.

For environmental impact analysis, the seafloor in the vicinity of the Demonstration Project mooring sites and power cable route will be examined using side-scan sonar to provide back-scatter imaging. For areas of particular interest identified during the side-scan survey (e.g. hard substrates that may be special habitats), surveys using video and selected submersible coverage (manned by qualified biological experts) will be carried out to assess benthic habitats that could potentially be affected by the mooring or operation of the plant.

Qualified marine biologists will identify and characterize the biological communities that might be affected by the cable installation using existing information. Divers will conduct more intensive bottom surveys of shallow-water biological communities present in near the cable landing site.

Key Nekton Species Special Studies

Special consideration is needed for threatened and endangered species. In this case it will certainly involve marine mammals, sea turtles, and seabirds but other protected or commercially important species that may occur at the water intake and discharge depths must be identified and addressed as well. Nekton are actively swimming aquatic organisms, able to move independently of water currents, such as fish and marine mammals. Specialist consultant reviews of existing studies of these species will be undertaken in conjunction with the other water column baseline data collection efforts. For example, such studies may analyze the sound measurements that are obtained from the moored arrays during baseline data collection to determine the kinds of marine mammals present near the site and the frequency of their visits.

Terrestrial Studies

Studies will be carried out in the second year to characterize the flora, fauna and potential historic resources of the areas potentially impacted by the land-based facilities associated with the cable landing and on-land support facilities. This work will depend in part on the availability of site-specific design information for the cable landing and support facilities.

Cultural Impact Analysis

A key component of the initial impact analysis in Hawai‘i will be a thorough Cultural Impact Analysis (CIA). This study will examine the potential project impacts to native Hawaiians through studies of local cultural practices and values and interviews of elders on O‘ahu. It is crucial to initiate the study early in the process to ensure that native Hawaiian views are considered through all the impact analysis and permitting work.

3.5.3.3 Proponent's Environmental Assessment, Management and Monitoring Plan (C1300)

The Proponent's Environmental Assessment, Management and Monitoring Plan (PEAMMP) would synthesize a project-specific impact assessment and impact management plan based on the proposed OTEC Pilot project at the proposed project site. Upon receipt of this information, the Navy as lead agency would review and evaluate the veracity of the information and use it as appropriate in preparing Navy NEPA documentation, perhaps through separate contract. This OTEC Pilot EMS element includes:

C1300 Proponent's Environmental Assessment, Management & Monitoring Plan

- C1310 Draft PEAMMP
  - C1311 NEPA scope
  - C1312 Compliance plan
  - C1313 Impact assessment
- C1320 Final PEAMMP

This EMS system element calls for subjecting design decisions made during FEED to a preliminary impact assessment. At this level, environmental analysis considers system element alternatives which would avoid or minimize adverse effects and enhance the quality of the environment. At a minimum this would allow engineers to confirm that the design can comply with applicable environmental standards, but it could also include more ambitious targets decided upon by project proponents who wish to exceed the minimum requirements. During this time the Developer has the opportunity to weigh development objectives against adverse environmental effects and to identify solutions compatible with the performance objectives.

Design requirements that exceed applicable environmental impact significance criteria are identified and design modifications are considered that will avoid or reduce impacts to less-than-significant levels. If this is not possible, the Developer weighs environmental impact against development objectives, documenting for the record consideration of design alternatives. The documentation will demonstrate for any unavoidable significant impact that no practicable alternative exists in the light of engineering, logistic and financial considerations. Upon

completion of this exercise, the Developer and Navy will understand the potential environmental effects of the proposal. Such an understanding will allow the Developer and Navy to respond effectively to agency inquiry during the NEPA documentation, permitting, and licensing procedures.

The "heart" of the NEPA process is the comparison and consideration of alternatives. Reasonable alternatives are those that meet the action's purpose and need, and achieve its objectives. The Preferred Alternative is the option that is preferable to the Navy during the NEPA process. The Navy decision-maker is the signatory official for the Finding of No Significant Impact (FONSI) or the Record of Decision (ROD). The agency Preferred Alternative may be different from an environmentally preferred alternative, depending on agency consideration of engineering, logistic and financial requirements.

A final alternatives list would follow evaluation of action variables, tradeoff studies, and environmental scoping under NEPA. This report presents an initial listing of variable OTEC factors which could lead to alternatives (Table 3-81). Variation in location, technology design or infrastructure can be used to create a set of reasonable alternatives that comply with NEPA regulations to meet the action need and achieve the action purposes. To define realistic alternatives, Table 3-82 lists topic areas that will be updated and resolved in the PEAMMP. Environmental team collaboration with Integrated Project Teams and tradeoff studies will help develop an accurate and realistic alternatives list for Navy use.

Table 3-81. OTEC Pilot Options as a Function of Siting Location

Variable	Possibilities (Alternatives)	Notes
Land-based Location	Only practical in a very few locations	Eliminated from consideration, since its design & development does not have general applicability
Platform Location	Non-Hawai'i locations Kahe Pearl Harbor A Pearl Harbor B PMRF Marine Corps Base Hawaii	Non-Hawai'i sites eliminated early due to lack of suitable infrastructure availability for prototype development A clear rationale for a Navy site preference consistent with the proposed action and linked to action needs and purposes will avoid risk of having to conduct detailed environmental site analysis at other sites. Pearl Harbor sites A and B may be used as alternatives. However, site alternatives A and B may not differ much from one another, thus appearing to be a construct.

Variable	Possibilities (Alternatives)	Notes
Cable route & shore landing	Direct, line-of-sight route to each landing point Indirect route to each landing point avoiding sensitive features Landing on Naval facility Landing on private/State shoreline HDD or trenched shallow water burial	Site preference documentation required. Impact assessment would be augmented with geographic spatial planning for ecological and biological sensitivity, recreational fishing and military restrictions. Cable trenching vice Horizontal Directional Drilling (HDD) or laying would require extensive additional permitting & environmental analysis
Interconnect Provisions	Tie with Existing Substation Construct new substation	Interrelated with site selection

Table 3-82. OTEC Pilot Options as a Function of Infrastructure or Management Variable and/or Tradeoff Analysis.

Design Parameter	Possibilities (Alternatives)	Notes
OTEC Facility Type	Open Closed Hybrid	Closed system currently in design. Engineering rationale needed to demonstrate selection.
Scale of Project (Power Output)	2 - 10 MWe	Trade project expense with minimal requirements to provide environmental data
Cable Design	Select Sturdiest Capacity Lowest Electromagnetic Field (EMF) or EMF not considered Cheapest	5 – 10 MWe currently conventional technology Minimize cost by selecting smallest size and only 5-year life (durability)
Discharge Design	Discharge Depth Separate or Mixed Discharges Discharge nozzle configuration	Depths under consideration for the discharge are between 50 & 150 m Current design calls for mixed discharge Flexibility of the discharge design would be preferred to allow monitoring of discharge impacts and responsive impact management during Pilot only
Water Production and Delivery	Platform Land	Dependent on related system trade study
Platform Configuration	Semisubmersible platform Spar Vessel	Semisubmersible is the current design Engineering rationale needed to document selection

Design Parameter	Possibilities (Alternatives)	Notes
Anchoring	Gravity Plow-type Drilled	Will depend on cost and seabed characteristics Placement must consider avoidance of hard-substrate habitats
CWP Construction Method	Construct onsite Construct ashore	Onsite construction feasible for pilot plant
CWP Size	4 m (effective, single or multiple pipes)	Dependent on the relationship between size and power output Engineering rationale needed to document selection Environmental planning would identify mitigation design criteria relative to intake velocity and screening
Operational Pattern	Continuous Discrete	Continuous provides better opportunity to judge the readiness for commercial-scale operation and to observe longer-term environmental effects Provides better opportunity for power sales to cover substantial portion of costs Discrete (intermittent) operation allows for more operational experiments
Intake Design	Variable screen sizes Variable intake areas No screen for cold water	Need to identify the specific screen sizes that will be tested (in lab and at-sea) Need to identify the intake velocities (and, therefore, intake areas) that are of interest Need to provide for w/ and w/o screen testing
Bio-fouling Management	Continuous, low level Periodic, higher level Active / passive	If chemical, need to identify substances that would be effective Need to establish release limits for biocides
Generator-heat exchange configuration	Combined evaporator and condenser Separate evaporator and condenser	
Working Fluid	Ammonia, Ammonia Water Mix	

Design Parameter	Possibilities (Alternatives)	Notes
Security Measures	Total exclusion zone around platform Regulated activities around platform No limits except for private property	Need to establish what is allowable under current regulations Need to assess threats (and their consequences) Need to identify enforcement resources/regime for each
Acoustic Signature	Variable by component	Sound isolation for individual components needed for supporting analysis.
Visual Appearance	Color Height Silhouette	

Environmental impacts are always specific to the project and site proposed. However all OTEC proposals must consider in detail the biological impact issues identified in Table 3-83. This list is not intended to be comprehensive, as any project-specific impact analysis must consider issues unique to the site and technology implementation; however, it does identify the key issues that merit early and rigorous consideration in virtually all circumstances. Social, cultural, historic, and economic factors are inherently very site-specific and project-specific.

Table 3-83. OTEC Pilot Key Biological Impact Issues

Resource	Project Activity/Component That is the Source of Impact			
	Construction & Decommissioning	Platform Presence (e.g. shade, noise, lighting)	Water Intakes (entrainment & impingement)	Water Discharges (secondary entrainment & contamination)
Plankton & Micronekton	○○○	○○○	■■■	■■■
Nekton	○○○	■■■	■■■	■■■
Marine Mammals	○○○	■■■	■■■	■■■
Sea Turtles	○○○	■■■	■■■	○○○
Birds	○○○	■■■	○○○	○○○
Benthos	■■■	■■■	○○○	○○○

Source: Extracted from common elements presented in [3], & [33] – [38]

Key: ■■■: potentially significant impacts

○○○: probably insignificant

As shown in the table, potentially significant impacts could result from each of these sources on some environmental resource. However, the construction, decommissioning and platform issues have relevant precedents in the oil and gas industry(MMS 2001); while the impacts associated with the water intakes and discharges are unique. A very large flux of surface warm water will be required for the evaporator cycle of the system and similar flux rates of deep, cold water will be necessary for the condenser cycle of OTEC systems. The scientific literature suggests that these water intakes and discharges are the most important sources of potential environmental impact for OTEC (Myers, Hoss et al. 1986). The importance of the potential environmental effects of water movement was noted at the recent NOAA Workshop which assessed the potential environmental impacts of OTEC technology (MacDonald 2010).

The PEAMMP is submitted to the Navy upon completion according to schedules collaboratively set by the Navy and the Developer. The impact assessment provided by C1300 is dependent on input information from the first increments of environmental baseline data obtained during by C1225 Baseline Data Collection. We anticipate baseline data will confirm historical oceanographic measurements made in and around the Hawaiian archipelago. As environmental baseline data trends are confirmed through continuing field work and compared with the historic literature, the impact assessment conclusions will be reviewed and revised in consultation with Navy environmental personnel.

3.5.3.4 Permits (C1400) and Consultations (C1500)

In parallel and integrated with Navy NEPA document production, the Developer will also prepare project-specific permit applications and protected environmental resource assessments for use by Navy under its lead agency role.

The technical objective of the Permits and Consultation system elements is to develop a specific technical approach for obtaining the approvals necessary to develop, fabricate, install, and operate an OTEC Pilot Plant facility. Preliminary Planning has identified the key permitting information inputs needed to obtain all major permits in addition to NEPA documentation required in order to develop a Pilot Plant at that location. See also Appendix 3.5-1 for a more detailed listing of relevant selected environmental laws, regulations and guidance. The Navy Environmental Readiness Program Manual, OPNAVINST 5090.1C, presents a comprehensive reference for Navy environmental planning policy compliance.

To complete the EMS Permits and Consultations elements, the Developer will assist the Navy in confirming with appropriate federal and State of Hawai‘i agency representatives the permits required and obtain guidance for applications (Table 3-78). Using this information, the Developer in consultation with Navy would prepare accurate OTEC Pilot permit applications and protected resource effects analyses. This documentation would be in draft form for Navy use as appropriate in applying for permits and conducting environmental compliance as lead federal agency.

The level of environmental impacts anticipated from implementing the OTEC Pilot project would be documented in NEPA documents prepared by Navy under separate contract. The NEPA document will consider all relevant environmental impact issues including the status of compliance with environmental laws that would be triggered by the proposed OTEC Pilot.

As presently contemplated, the OTEC Pilot project will be a small-scale (5 to 10 MW) facility that the U.S. Department of Energy will designate as a "Demonstration Project" and will not require a NOAA license under the OTEC Act. Department of Energy does have the authority to apply environmental requirements from the OTEC Act as appropriate during this process. As there are no current regulations governing this process, any changes in OTEC Act requirements would be addressed upon initiation of the EMS Planning and Permitting segment for a Navy OTEC Pilot project.

The potential entrainment of biota in the OTEC water intakes and impingement of biota on intake screens will be focal issues under the Endangered Species Act (ESA), the Marine Mammal Protection Act (MMPA) and the Clean Water Act (CWA) permit acquisition. Coordination with systems engineering would apply EPA thresholds for water intake velocity and discharge plume pollutants that it currently uses for power plant cooling water. The EMS procedures outlined here provide the Developer opportunity to consider more cost-effective, but environmentally equivalent options. Such alternatives may be accepted by regulatory agencies upon clear demonstration of equivalent environmental impact to sensitive resources and habitats.

The design of the OTEC Pilot will require a point-source discharge authorization by the Environmental Protection Agency (EPA) under the Clean Water Act §402. This authorization, known as the National Pollution Discharge and Elimination System (NPDES) permit proscribes effluent thresholds for priority contaminants and intake and discharge velocities. We expect EPA to issue this permit with Special Conditions that require monitoring of the discharges and the potential for mandatory corrective procedures, including cessation of operations, depending on the results of the monitoring.

Potential impacts to protected species, their habitats and essential fish habitat would be focal issues under the Endangered Species Act and Magnuson-Stevens Fishery Conservation and Management Act. While the net effect on listed species after application of mitigation is a determination of the lead federal agency, consultation with the US Fish and Wildlife Service and NOAA Fisheries may develop additional conservation measures applied to the project. Thus, completion of consultations under these laws is usually required in order to complete the NEPA process.

Coastal Zone Management Act (CZMA) compliance will consider federal consistency with the State of Hawai‘i coastal management program. If Navy exercises the federal navigational servitude doctrine no leases from submerged land owners, including the State of Hawai‘i, would be required.

The NEPA impact analysis will provide an assessment of effect on protected marine mammals under the MMPA. The MMPA sets a moratorium on the "take" of marine mammals. Authorization for incidental takes, including both harm and harassment of marine mammals is a permit-like process administered by NOAA. Preliminary collaboration with NOAA is recommended to identify specific take thresholds that can be addressed during NEPA impact analysis.

Under the National Historic Preservation Act and related laws, the precise siting of cable routes and anchors would consider the potential of adverse effect to historic and archeological resources. Under the Resource Conservation and Recovery Act (RCRA), the use, storage and

handling of hazardous wastes and materials are considered. The direct compliance requirements of the Clean Air Act (CAA) will not be triggered; however, NEPA analysis will consider the potential air quality pollution emissions generated by the OTEC Pilot project operations and EPA requirements for air quality emissions during construction and operation.

The OTEC Pilot project may be within the jurisdictional authority of the Department of the Army in administering the Clean Water Act and Rivers and Harbors Act. Discussions in 2008 indicated the OTEC Pilot is outside Army Corps of Engineers Honolulu District jurisdiction. However, federal regulations defining the extent of waters of the United States and navigable waters may be revised before OTEC Pilot Planning and Permitting occurs. Prior to applying for Army Corps of Engineers authorization, the Navy may request a jurisdictional determination from the District Engineer[7], who can make a formal jurisdictional determination for a specific proposed action. The jurisdictional determination will identify whether the proposed OTEC Pilot project will be subject to the regulatory authority of the Army.

The type of construction involved in the OTEC Pilot project is not usually associated with the discharge of sediments triggering Clean Water Act permit procedures. Therefore, the project likely will not require a Department of the Army Clean Water Act §404 permit or the associated Clean Water Act §401 Water Quality Certification. Power cable installation will be conducted in such a manner so as not to discharge sediment and thus trigger the Clean Water Act. The OTEC Pilot project may present a potential obstruction to navigation, potentially requiring Department of the Army authorization under the Rivers and Harbors Act §10.

The Department of the Army authorization is not required by federal NEPA regulations to complete the NEPA process. However some Navy commands require permits to be complete before approving the NEPA documentation to ensure adequate documentation of mitigation requirements.

No local permits would be required for the Navy OTEC Pilot that includes a cable landfall on federally-owned property. If the landing is on land under State of County jurisdiction, a Special Management Area permit would be required from the County, as well as an easement from the landowner(s) across whose property it passes.

While some approvals will be needed regardless of location, others are specific to the location ultimately selected for the facilities. Moreover, many of the specific activities (e.g., baseline data collection, site-specific analyses, public outreach, etc.) required for permitting an OTEC facility are highly dependent on the location and specific system selected for the installation. In particular, a thorough environmental sampling at the selected site and analysis of the collected samples are required to characterize adequately the biological and oceanographic parameters of the selected Pilot Plant site.

[7] US Army Corps of Engineers, Honolulu District (http://www.poh.usace.army.mil/)

3.5.4 Operation and Monitoring Segment (C2000)

The OTEC Pilot EMS Operations and Monitoring segment builds on the foundation established during C1200 PEAMMP preparation. Design features and plans will have minimized the environmental impact of constructing, operating and decommissioning the Navy OTEC Pilot project. Through the NEPA process and integrated permits and consultations procedures additional environmental management and monitoring features would have been added. These features will comprise the OTEC Pilot project environmental aspects to be implemented at the beginning of construction and maintained throughout the life of the project. Monitoring requirements developed during Planning and Permitting will provide feedback information to validate impact predictions or correct for exceedances. The OTEC Pilot EMS Operations and Monitoring segment includes:

C2000 Operations and Monitoring Segment

- C2100 Setup
  - C2110 Environmental operating criteria
  - C2120 Management procedures
- C2200 Adaptive Management
  - C2210 Monitor commitment, impact and scope alignment
  - C2220 Assessment
  - C2230 Stakeholder review and acceptance
  - C2240 Corrective action definition
  - C2250 Corrective action implementation

Our approach will reduce total life cycle cost by emphasizing impact management as well as pollution prevention. The overarching environmental management plan developed earlier is the foundation for a proactive stance for meeting or exceeding the letter and spirit of current and future environmental requirements.

This segment of the OTEC Pilot EMS is the framework for guiding our integrated program to achieve and maintain environmental compliance in accordance with environmental goals, changing regulations, social, economic, and political pressures and environmental risks. The segment activities are on a continual cycle of monitoring, assessing and improving to meet environmental obligations. During Setup activities, the Developer will establish and implement a process for measuring and improving environmental performance. Specific details needed to complete a full Operations and Monitoring segment will have been prepared during Planning and Permitting.

3.5.4.1 Setup (C2100)

Once permits have been granted and the OTEC Pilot project is underway, the environmental monitoring framework is used by the Developer to establish monitoring procedures at the operational level. These operations and monitoring activities use an adaptive management approach very similar to typical process improvement activities. Documentation developed during Planning and Permitting will tell the operations team what environmental conditions (emissions and ambient) to monitor, the frequency of monitoring and, in some cases, the required response to certain measurement ranges. Project-specific environmental goals and absolute limits also will be available. The objective of an adaptive management approach is to measure actual environmental impacts and compare these findings to previously established targets, both regulatory and internal. The operations team will develop plans for responding to any exceedances that occur. In some cases the response will involve no more than regulatory reporting. In other cases, immediate changes in operational procedures may be required. In all cases the data will feed into the same engineering reviews to which other operational results contribute so that the lessons learned can be used to improve future performance.

Documentation

To effectively communicate with Navy, regulatory agencies and the public, the EMS Operations and Monitoring will be documented. During Setup, documentation structure will be implemented. Documentation will describe the core elements of Operations and Monitoring, metrics, thresholds and standards. Consistent with ISO standards, the documentation will address environmental policy, organizational structure and key responsibilities, descriptions of how our policies and procedures comply with ISO standards.

Environmental records will be legible, identifiable, and traceable to the system and element involved. Environmental records shall be stored and maintained in such a way that they are readily retrievable and protected against damage, deterioration or loss. Their retention times will be established and recorded.

Document Control

EMS documentation shall be maintained and included in the OTEC Pilot project document control system as a component of overall project data management. Documents, including such as environmental management plans, pollution prevention plans, environmental compliance plans and hazardous material management plans will be included. Other items such as training material, records of communication, applicable laws and regulations, Standard Operating Procedures, Occupational Safety and Health Act (OSHA) Right-to-Know documentation, Material Safety Data Sheets, etc. will be maintained and made readily available.

Operations Setup

Plans and procedures will be finalized and implemented in preparation for construction. These will be documented and monitored for performance effectiveness in addition to environmental impacts. The goal is to identify not only impact management best practices but also operational management best practices.

Consistent with ISO requirements, OTEC Pilot EMS will include appropriate auditing to determine whether ongoing activities are in conformance with operational criteria. The purpose of the audit is to maintain management focus on the environment, determine whether the system conforms to the planned objectives of the EMS, improve the EMS, and ensure its cost-effectiveness. It shall be conducted at least annually, the results documented, and the documentation retained.

3.5.4.2 Adaptive Management (C2200)

The objective of adaptive management is to improve the state of knowledge from experience and applying that knowledge to the project at hand. For the OTEC Pilot project, the knowledge gained is also passed onto design and operation of future OTEC Commercial projects. In the face of uncertainty, adaptive management provides for flexibility in adapting to previously unknown situations. This is especially helpful with a nascent technology such as OTEC. Adaptive management also will provide for reasonable actions in response to improvements in environmental impact knowledge.

Successful adaptive management is based on an executive leadership commitment to beneficial change. It operates through collaboration among Developer, the Navy and external stakeholders. The entire program is based on clearly defined objectives that would be developed during Planning and Permitting. These objectives are keyed to environmental impact uncertainties defined as testable hypotheses. The monitoring program tests specific parameters for the purpose of reducing uncertainty. Therefore, program continuity as provided for in this EMS is essential to success.

In a recurring series of five elements (C2210 through C2250), the environmental impact of constructing and operating the OTEC Pilot plan is monitored and responsive actions identified and executed. The Developer identifies any exceedances and develops design modifications to bring environmental data back into conformance with commitments developed during C1000 Planning and Permitting. The proposed response is submitted to Navy and stakeholder consideration for acceptance. Upon acceptance, design modifications are put into place with recurring monitoring noting changes in environmental response data.

Operational Control

Once construction has commenced the EMS operations, workflows, and processes are implemented. It is especially important to establish and maintain these procedures for those situations where the absence of these controls could lead to deviations from the environmental policy, thresholds and standards. The Developer in consultation with the Navy provides management oversight and control of these operations and is responsible to ensure procedural compliance.

The cycle of monitoring, assessment, corrective action, approval and execution would continue throughout the OTEC Pilot operation. At each cycle, the Lead Agency, regulatory agencies and other stakeholders would have opportunity to review the status of the program. The Lead Agency would likely have the authority to approve or deny implementation of any particular corrective action and to stop the OTEC Pilot project in extreme cases.

Monitoring and Measurement

The Adaptive Management element will include procedures to monitor key environmental impact parameters identified during C1000 Planning and Permitting. These parameters will include potentially significant environmental impacts. Procedures will include measures to track environmental performance, such as how well objectives and targets are met, and a plan for internal auditing. The internal auditing will evaluate OTEC Pilot compliance with applicable laws and regulations as well as progress or lack thereof in meeting the commitments developed during Planning and Permitting.

Nonconformance, Preventive and Corrective Action

The Adaptive Management element will include procedures to correct systems deficiencies as they are encountered. This process shall provide for investigation of problems and nonconformity, identification of root causes, implementation of corrective actions, and documentation of all findings.

Corrective or preventive action taken to eliminate the causes of actual and potential nonconformance will be appropriate to the magnitude of problems and commensurate with the environmental impact encountered. The Developer will implement and record any changes in the documented procedures resulting from corrective and preventive action.

Emergency Preparedness and Response

The Adaptive Management element will include an emergency preparedness and response program for OTEC Pilot construction, operation and decommissioning. The program will assess the potential for environmental mishaps and emergencies, describe procedures for preventing incidents and their associated environmental impacts, plan for responding to incidents, periodically test emergency plans, and provide for mitigating impacts associated with environmental incidents.

The OTEC Pilot EMS will adapt existing ocean engineering environmental operations programs as practicable. Such facilities are operational currently and are in full compliance with waste handling requirements and occupational safety and health requirements such as worker safety and community right-to-know regulations. OTEC Pilot-specific emergency preparedness and response plans will be developed for facilities and operations not covered under existing plans. Requirements for these specific activities will be determined during the Planning and Permitting segment.

3.5.5 Risks

The environmental program activities are on the critical path toward a successful implementation of the Navy OTEC Pilot project off Oahu. It is important to understand the key risks and how the EMS manages these risks.

Late Start

Late start of environmental planning and compliance activities is a problem that adversely affects implementation schedules. For Navy project execution tied to federal spending rules, potential fund expiration and competing Navy projects, a timely construction start is essential for

implementing OTEC at any scale. Congressional authorizations are limited to certain obligation windows. Most large Navy programs are planned many years in advance of the start date. Missing an execution window could result in failure of the entire project because of funding expiration. Because many schedule delays are cumulative, a month's delay in one system element could mean the difference between life and death for a Navy OTEC Pilot project. The EMS manages this risk by early planning managed by the Developer integrated with design and consistent with federal environmental policy. The EMS pathway identifies a compliant environmental process and milestones required to achieve a timely start for a Navy OTEC Pilot project. Integration with design, early assessment of impacts and impact mitigation and a maturation of technology-specific environmental knowledge are features of the EMS that minimize the risk of late project execution.

Discontinuity

Loss of knowledge continuity both within the Developer team and between the Developer and Navy also would risk successful completion of the OTEC Pilot project. Furthermore, the Developer must maintain continuity between the OTEC Pilot and future OTEC Commercial projects. Thus, the husbanding of environmental impact management knowledge throughout the program is critical. The consequences of discontinuity are duplication of effort and errors of omission and commission ranging from inconsequential to serious. Illogical non-value added activity is generally associated with discontinuity due to the failure of base plans and milestones. The EMS manages this risk with the responsibility for the Developer to retain and apply knowledge toward the immediate OTEC Pilot goal and a future OTEC Commercial goal. Appropriate milestones are included to ensure the immediate OTEC Pilot is environmentally compliant and according to Navy requirements.

Internal Controversy

A major risk for any environmental program is within-team miscommunication and controversy. The consequences of miscommunication and controversy are generally extended schedules and cost escalation ranging from inconsequential to catastrophic. Controversy within the project team is manifest by confusion and uncertainty when viewed from the outside. Because environmental programs ultimately are publicly visible, the appearance of confusion and uncertainty would damage the credibility of the Developer and the Navy OTEC sponsor for the Navy chain of command, regulatory agency personnel and the public at large. The EMS which embodies a strong Developer lead role provides measurable milestones and procedures for team members to adhere. A structured Developer procedure provides verification and authentication documents that are the authority and commodity by which the Developer formally communicates with the Navy. Team discussions are encouraged, but "stovepipe" decisions are discouraged. Through a structured document production, information flow is contained and captured for project management control change handoff between Developer and Navy.

Unforeseen Environmental Requirements

Similar to late start risks, late application of environmental requirements can cause an entire project to stop accommodate the "new" requirement. Such an event may stem from "new" requirements from environmental or design sources. The risk of "new" and untimely environmental requirement is always present because of the wide variety of agencies, individuals

and viewpoints involved in the environmental planning and permitting activities. The EMS minimizes this risk through a systematic involvement of the environmental functions with design functions. Design and environmental information is cross referenced during FEED providing a comprehensive project design that addresses known environmental issues in a timely manner. Conflicts between environmental and design criteria would be unearthed at an early time allowing sufficient opportunity for resolution. The experience is documented and available for Navy NEPA documentation as the basis of compliance. This activity is managed by the Developer who provides the Navy with a product that has undergone extensive environmental review. The objective is documented evidentiary support that avoids argument from ignorance (*argumentum ad ignorantiam*), including negative evidence and lack of imagination. When well supported information is presented to regulatory agencies and the public, unforeseen environmental issues are fewer in number and more easily managed.

Disorganization

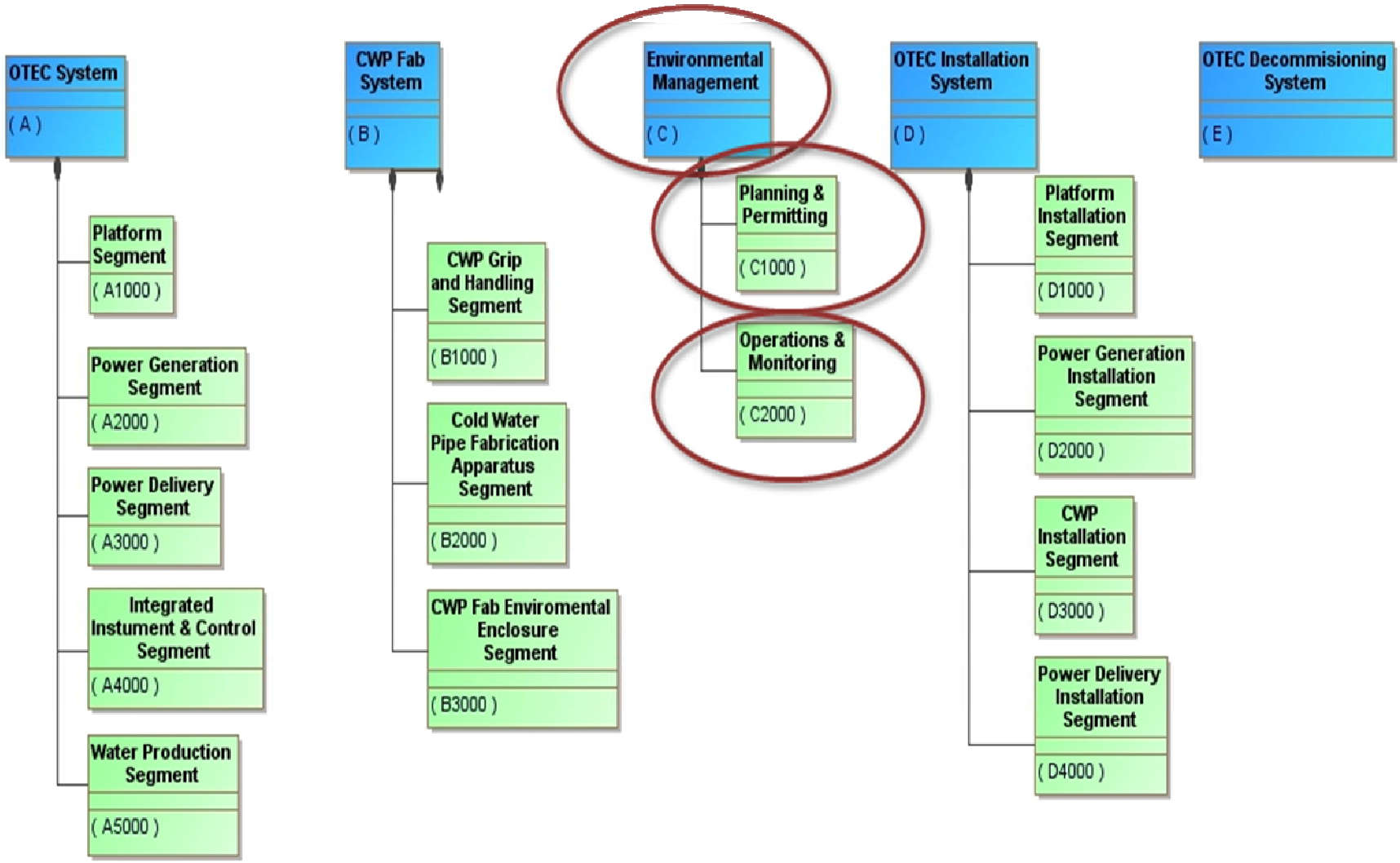
Similar to miscommunication, out of sequence task accomplishment can occur with projects having a complex sequence of events with required predecessor and successor tasks. Out of sequence task accomplishment generally causes frustration among team members, but can also seriously delay or add costs to a project. The EMS provides a logical sequence of tasks designed to provide environmental compliance in a smooth and efficient flow. Large and long-term environmental programs are particularly sensitive to out of sequence tasking. The EMS Planning and Permitting segment manages this risk by providing a logical flow of literature review and gap analysis, baseline data collection, impact assessment and mitigation and objective-based monitoring planning providing a seamless input to the Operations and Monitoring segment with minimal control handoffs and opportunity for Navy to exert its discretional authority.

Premature Action

A significant risk for Navy NEPA document production involves a premature action based on an incomplete site preference. The NEPA documentation for an OTEC Pilot project must present a complete and coherent rationale for site selection; either part of the NEPA scope as an element of purpose, or part of the NEPA impact analysis as an element of impact comparison. Without careful preparation, there is a risk the NEPA document would fail to provide either a coherent rationale for site selection and also not providing the requisite comparison. Without supporting documentation for site selection or a comparison of impacts involving various sites, the NEPA document would be open to litigation. Regardless of which site Navy prefers, the EMS continues to function in support of a successful OTEC Pilot project. Information provided by the Developer is specific to the Navy preferred site. During Baseline Planning activities, the EMS provides opportunity collaborative resolution of environmental issues such as siting preference before prematurely embarking on one direction.

These strategies can be modified as needed to accommodate Navy requirements and, perhaps, new NOAA OTEC regulations. Regardless, the EMS provides a functional and compliant strategy that can be modified when vetted at the highest levels and known to the entire Developer-Navy team.

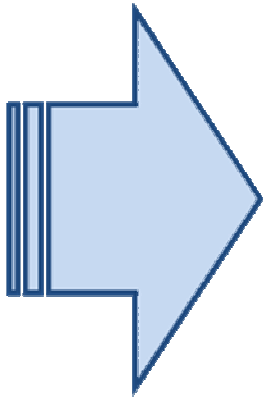
3.5.6 EMS Brief



Environmental Management Planning

Factors

- ✓ Proponent initiates action
- ✓ Funding source(s) may be simple, hybrid or composite
- ✓ NEPA lead retained according to agency discretion



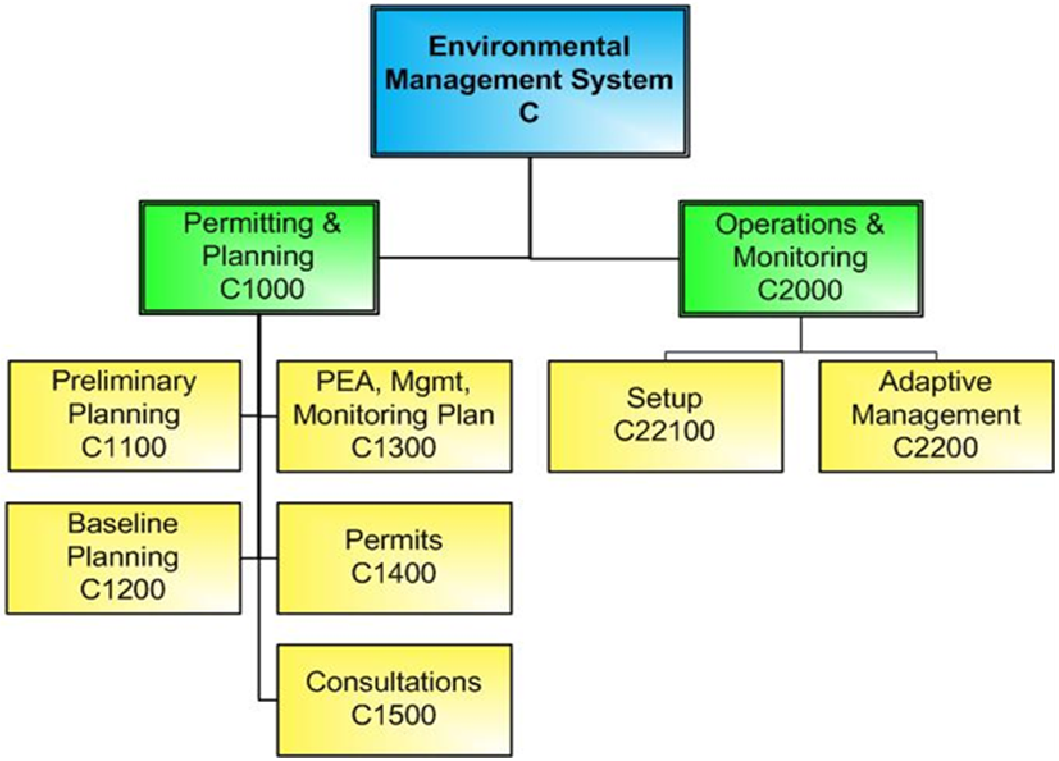
Scenarios

- ✓ <u>Federal scenario</u>
  Federal simple funding
  Federal hybrid funding
  Funding or Regulatory Lead
- ✓ <u>Private scenario</u>
  Private investment funding
  Composite hybrid funding
  Regulatory Lead

Key Objectives – Environmental Management

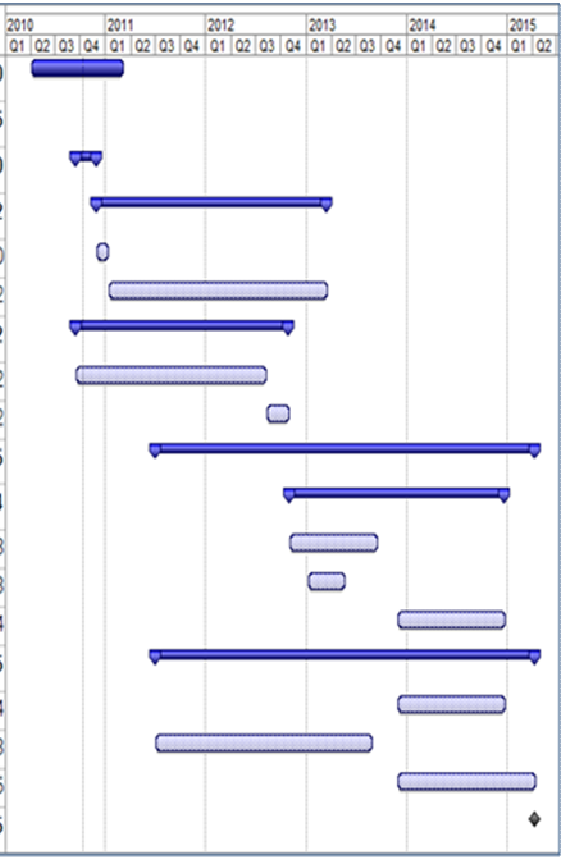
Objective	Source	Rationale	Impact
Comply with ISO 14000 (Environmental Management)	Systems Engineering Participation	Foundation for Environmental Compliance	Develop Environmental Compliance Continuity
Identify & Define EMS for Pilot Project	Project Management Prerequisites	Roadmap for Environmental Project Execution	Provide Effective Project Management
Obtain Permits & Complete Environmental Assessment	Applicable Federal & State Laws	Milestones for Environmental Compliance	Improve Efficiency Avoid Delays & Denials
Define Operational Monitoring Requirements	NOAA, Scientist & Stakeholder Views	Facilitate Approval of Impact Assessment	Improve Commercialization Environmental Management

Environmental Management System Architecture

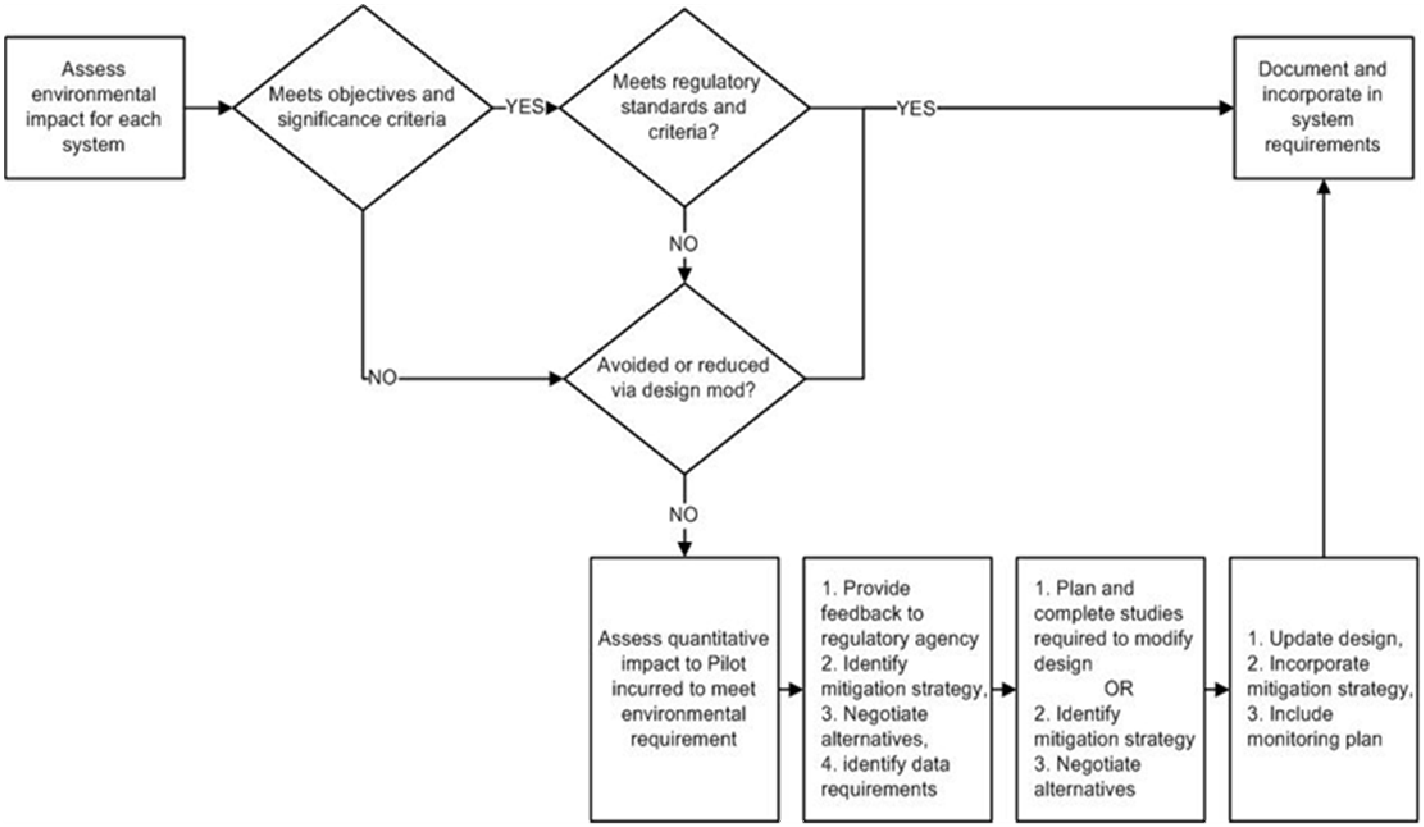


Environmental Planning & Permitting C1000
Preliminary Development Schedule

ID	Task Name	Duration	Start	Finish
1	Demonstration Designation	12 mons	January 1, 2010	December 2, 2010
2	C1000 Planning & Permitting	1195 days	June 14, 2010	January 9, 2015
3	C1100 Preliminary Planning (ongoing)	55 days	June 14, 2010	August 27, 2010
10	C1200 Baseline Planning (next steps)	600 days	August 30, 2010	December 14, 2012
11	C1210 EMS Requirements	30 days	August 30, 2010	October 8, 2010
13	C1220 Environmental Baseline Data	570 days	October 11, 2010	December 14, 2012
20	C1300 Proponent's Enviro Mgmt Plan	555 days	June 14, 2010	July 27, 2012
21	C1310 Draft PEMP	495 days	June 14, 2010	May 4, 2012
26	C1320 Final PEMP	60 days	May 7, 2012	July 27, 2012
30	NEPA EIS (by funding federal agency)	986 days	April 1, 2011	January 9, 2015
38	C1500 Consultations	560 days	July 30, 2012	September 19, 2014
39	C1510 ESA (formal)	230 days	July 30, 2012	June 14, 2013
43	C1520 NHPA	95 days	October 8, 2012	February 15, 2013
47	C1530 CZMA	280 days	August 26, 2013	September 19, 2014
51	C1400 Permits	986 days	April 1, 2011	January 9, 2015
52	C1410 & C1430 USACE	280 days	August 26, 2013	September 19, 2014
56	C1420 NPDES	560 days	April 1, 2011	May 23, 2013
61	C1440 MMPA	360 days	August 26, 2013	January 9, 2015
65	Implement	0 days	January 9, 2015	January 9, 2015



Environmental Planning & Permitting C1000
Permitting & System Design Feedback



Next Steps

What	When
Prepare Environmental Management Plan ✓ Proponent's environmental impact assessment ✓ Mitigation Plan ✓ Monitoring Plan	Qtr 1, FY11
Complete EMS Systems Engineering requirements	Qtr2, FY11
Initiate baseline data collection	Qtr2, FY11
Initiate NEPA (EA/FONSI or EIS/ROD TBD)	Qtr 3, FY11

3.5.7 Forward Plan / Next Steps

As noted above, C1100 Preliminary Planning has been completed with this report. Next steps would complete the remainder of the Planning and Permitting segment activities in sequence. The first step would be completion of the EMS Systems Engineering requirements and review of other system elements to systematically identify and resolve any conflict between environmental and design requirements. This step will conduct the activities of C1200 Baseline Planning and C1300 Proponent's Environmental Assessment, Management and Monitoring Plan:

- Environmental performance criteria, thresholds and standards
- Environmental information gaps
- Baseline data collection (sampling plan)
- Baseline data collection (field work)
- Proponent's environmental impact assessment
- Mitigation plan
- Monitoring plan

Upon completion of these tasks, the Navy would be positioned to begin its NEPA process and the Developer would embark on preparing submittal materials identified in C1400 Permits and C1500 Consultations.

3.5.8 Literature Cited

Broadeur, R. D., M. P. Seki, et al. (2005). "Micronekton - What are they and why are they important?" Pisces Press 13(1): 5.

CNO(N45) (2006). CNO letter 5090 Serial N456C/6U838243 of 4 October 2006; NAVY ENVIRONMENTAL PLANNING DOCUMENT PREPARATION PROCEDURES: 8.

MacDonald, D. A. (2010). Potential Environmental Impacts of an OTEC Facility. OTEC: Assessing Potential Physical, Chemical and Biological Impacts and Risks, Honolulu, HI, Coastal Response Research Center at the University of New Hampshire.

MMS (2001). Final Environmental Impact Statement, Proposed use of floating production, storage, and offloading systems on the Gulf of Mexico, Outer Continental Shelf, Western and Central Planning Areas. U. S. M. M. Service: 793.

Myers, E. P., D. E. Hoss, et al. (1986). The Potential Impact of Ocean Thermal Energy Conversion (OTEC) on Fisheries. NOAA: 39.

UN (1987). Our Common Future, Chapter 2: Towards Sustainable Development, Section IV Conclusion. G. H. Brundtland, UN: 20.

3.6 OTEC Installation System (D)

Installation Overview

This section describes the installation sequence and process for all the primary OTEC Pilot Plant segments. The relevant section of the OTEC System Hierarchy is shown below in Figure 3-193. This section will describe the following hierarchical segments:

(1) D-1000 Platform Installation Segment

(2) D-2000 Power Delivery Installation Segment

(3) D-3000 Cold Water Pipe Installation Segment

(4) D-4000 Power Generation Installation Segment

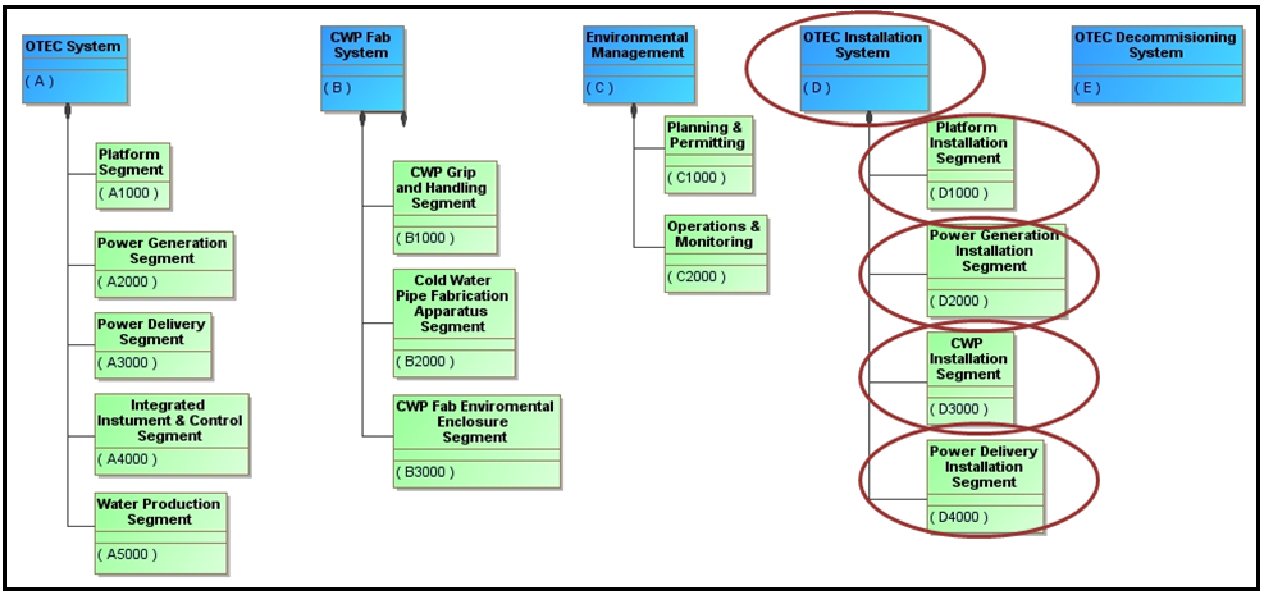


Figure 3-193. OTEC System Hierarchy - Installation Segments

Overall Installation Considerations

In planning the installation of the OTEC Pilot Plant and related cabling to shore, there are many variables and a high dependence between the (a) size and weight of the mooring components, (b) the length, size, and weight of the submarine power cable, (c) manufacturing location of the mooring components and submarine power cable, and (d) the costs and availability of offshore tugs and offshore construction vessels in the installation area. The Hawaiian location of the OTEC Pilot Plant drives the requirement for long-distance material transportation and the need for a Mobilization and Staging Area (MASA) in the Honolulu or Pearl Harbor area. The installation operations are defined to include transportation and key segments (platform, remora, anchors, tension members, and power transmission cable) to Hawaii. An overarching principal in installation planning is the operations be designed to be reversible, and to the extent practical, independent, to minimize risk, and to take maximum advantage of weather windows. It is also important take advantage of vessels of opportunity and whenever possible to share transportation

and installation assets. For this installation plan, we have made a number of baseline assumptions which establish the specifics of the plan. The major assumptions include:

a. The OTEC Site is off of Pearl Harbor on the west side of Oahu.

b. Major Segments are manufactured as follows:

   (1) Platform in Far East - Transportation via Tow - Ocean Going Tug.

   (2) Platform, remora, and mooring components in Gulf of Mexico; Transportation through PANAX

   (3) Submarine power cable manufactured in Europe; Transportation through PANAX

c. MASA established in the Pearl Harbor or Honolulu area.

d. Installation will be performed in relatively calm seas and generally in Sea State 2 or below.

Pilot Plant Location and Power Cable Routing

The platform is assumed to be installed in the location off of Pearl Harbor Hawaii as Figure 3-194. The Pilot Plant is located in 1100m of water and the power delivery cable run is assumed to be approximately 28 km, on the route approximately shown, with a shore-landing at either the Joint Base Hickam or Pearl Harbor Naval Station (Ref: Figure 3-195).

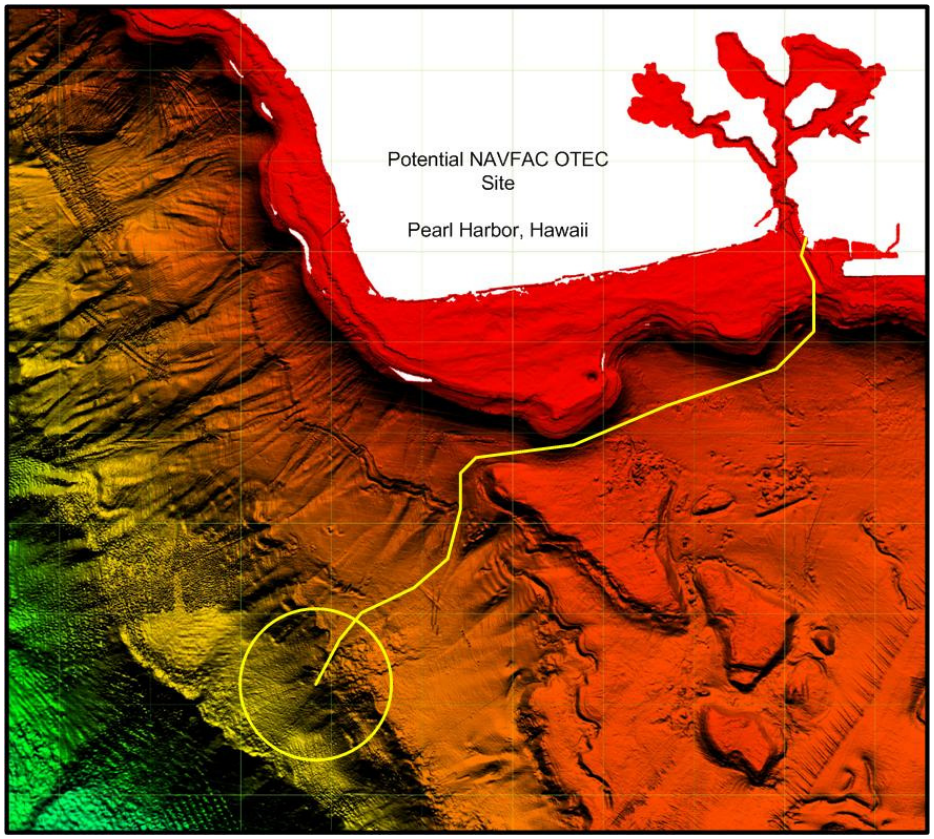


Figure 3-194. Pilot Plant Installation Location - Pearl Harbor

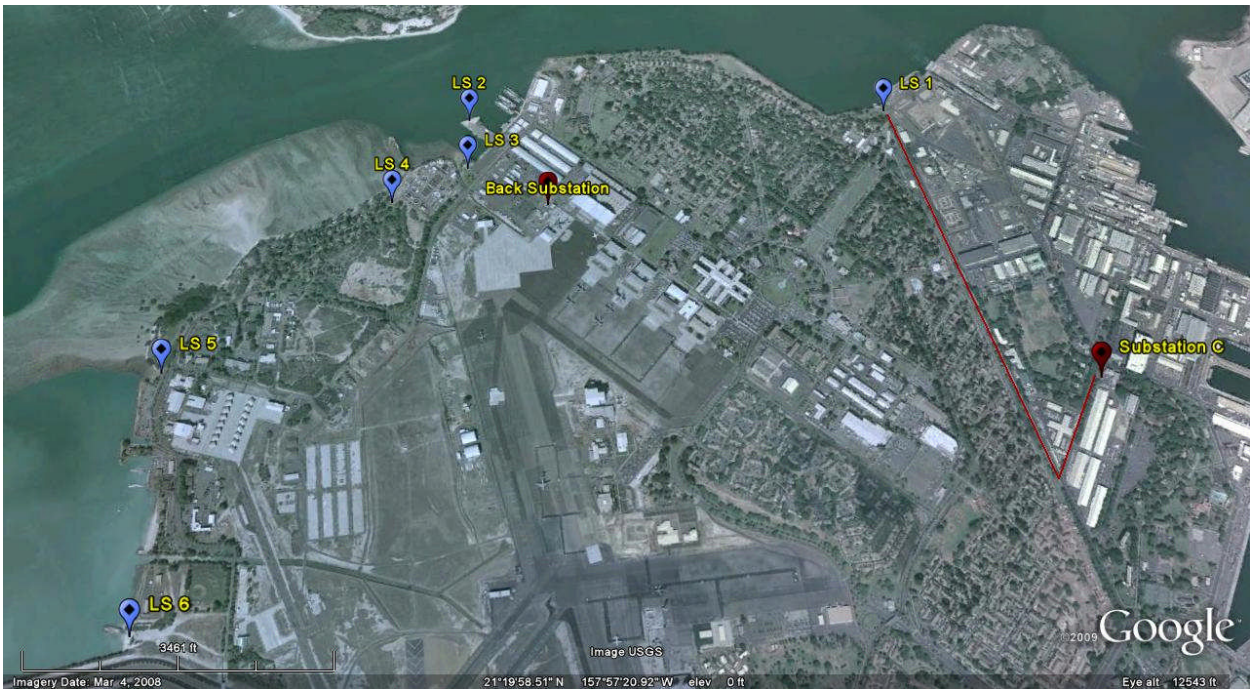


Figure 3-195. Alternative Shore Landings - Hickam and Pearl Harbor

The symbols (LS 1 through LS 6) in Figure 3-195 above reflect alternative sites being considered to land the shore cable. The grid interface will either be routed to the Back Substation and Joint Base Hickam or to Substation C at Pearl Harbor.

For purposes of mooring system sizing and installation planning the specific anchor locations and power cable landing is approximately as shown in Figure 3-196. While both four-point and eight-point moors have been evaluated, the eight-point moor has been assumed for this installation report. The platform anchor locations are assumed to be located off of the four corners of the semisubmersible platform and anchored into adequate sediment zones on each of the two plateaus (Figure 3-196). Tension member quantities, lengths, and sizes are shown in Table 3-84 below.

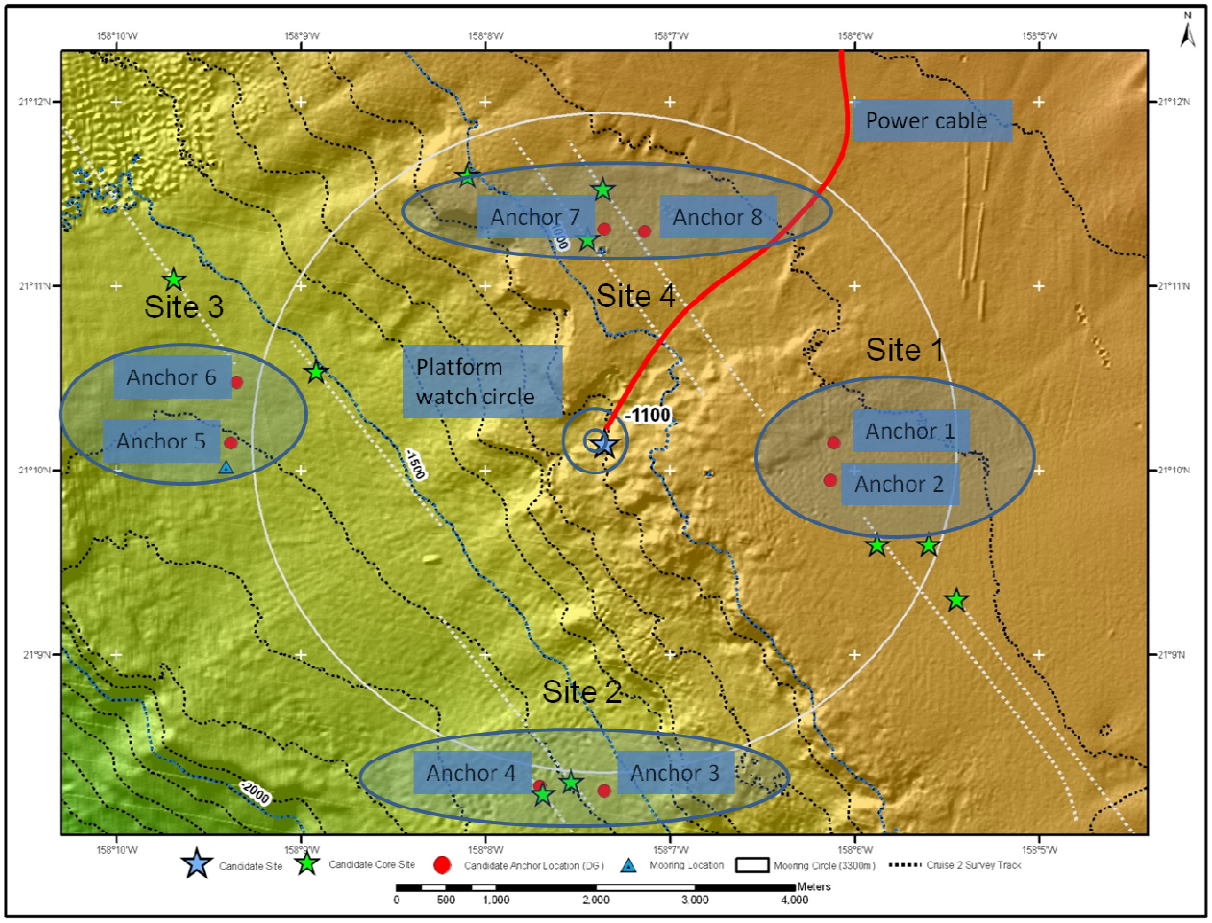


Figure 3-196. Eight Point Moor - Assumed Anchor Locations

Table 3-84. Mooring Tension Members - Eight Point Wire Moor

ELEMENT	QTY	SIZE	TYPE
CHAIN	8X 1000 m 8X 2000 m	4-1/8” (104.8 mm) Alt. 4 ½” (114.3 mm)	R5 R4
WIRE ROPE	2 x 2063 m 2 x 3770 m 2 x 3835 m 2 x 2075 m	2. 5” (63.5 mm)	GALV EEIPS 6X19 WIRE ROPE
ANCHORS	8	40 mT	Bruce FFTS MK4

3.6.1 Platform Installation Segment (D1000)

Platform Installation Driving Requirements

The objective of the mooring system design was to derive a low cost and low risk approach to mooring the pilot platform. This is made more challenging by the water depth, slope, and sediment conditions at the candidate OTEC site. Design is based on standard industry practices/guidelines (e.g. API RP2SK, ABS, etc), and anchors are sized to deploy from commercially available vessels or barges. Moorings are to be tested to appropriate proof loads prior to service. Accordingly, the key requirements for the platform installation are summarized in Table 3-85 below.

Table 3-85. OTEC Platform Installation - Driving Requirements

Requirement	Source	Rationale	Impact
Installations to be conducted in appropriate sea state and period to be based on hindcast weather predictions	Derived system requirements, OTEC Design Basis	Minimize component motions, installation loads and risks wherever possible	Install during relatively calm months of year
Mooring anchors to be proof loaded to 80% of max intact load	API RP 2SK Offshore Platform Code	Sets anchors and reduces risk of dragging during operation	Requires platform or other vessel proof load anchors prior to operation
Moorings installed first followed by platform, power cable and remora.	Derived system requirement	Order of events dictated by system hierarchy	Scheduling of installation vessel(s) and duration of installation Allows system performance to be verified prior to cable installation to reduce cost and risk
Anchors, chains, fairleads, and tensioners to be sized for production loads	Derived system requirement	Minimize cost impact during transition from pilot plant to production plant	Pilot plant component cost and installation loads

Design Decisions - Rationale / Trade Studies

The tradeoffs associated with OTEC Plant installation are tightly coupled with the mooring configuration and the estimated sizes and weights of the mooring components, particularly the seafloor anchors. The alternatives considered for platform and anchor installation were:

- Separate vessels sized and equipped to install (a) moorings and anchors, and (b) submarine power cable or,
- Single vessel used to install both moorings and power cable.

The alternatives for proof loading of the anchors included:

- Use the platform and tensioning system to proof test the anchors or,
- Use a separate installation vessel to install/proof the anchors prior to hookup to the OTEC Pilot Plant platform.

Other trades and alternatives included the order of installation operations, the method of shore landing, and whether the power cable should be installed from platform to shore or the reverse. The results for each of these in summarized with rationale in Table 3-86 below.

Table 3-86. Installation Design/CONOPS Trades

InstallationTrades	Results and Rationale
Single installation vessel for moorings and cable vs. separate vessels	Separate vessels due to: (1) Day rate and overall cost of all-in-one vessel outweighed additional transit time for two vessels (2) Additional flexibility in schedule of installations and location of vessels/equipment
Proof -test anchor with separate installation vessel or using OTEC pilot Platform and installed Tensioning System	Use OTEC platform due to operations efficiency and cost. Platform tensioning system can be sized to meet proof testing requirements for the Production Phase.
Power Cable Installation	From platform to shore allows cable to be laid up slope (preferred)
Shore end over beach or by HDD	HDD recommended to avoid damage, exposure, etc (Note: HDD may not be required at candidate landing site 2 (LS2)
Moorings Installation Order	Anchors first allows for precise installation location of anchors, allows for minimal interaction w/ platform
Remora installation	Platform pulls remora in versus tug pushing remora for mating, better control over remora and reduced loads

Platform Installation Resources and CONOPS

The selected anchor baseline was the Bruce FFTS - Mk 4 as shown below in Figure 3-197 below. To accommodate peak dynamic loads estimated for the 20-year Pilot Production phase a 40-ton configuration was selected for preliminary anchor sizing and installation planning purposes. While smaller anchors could be used to meet the requirements of the Pilot Phase, the 40 mT embedment anchors are easily handled by a wide range of offshore construction vessels. The primary drivers for installing the mooring system for the pilot plant involve the size of the seafloor anchors and the loads to which they should be proof-tested. A nominal additional investment in anchors and load testing during the original installation for the Pilot Phase will provide the opportunity to transition the platform to Production Phase in-situ at minimal cost.



Bruce FFTS - Mk 4 - Anchor

- **Weight** - 40 Tons
- **Nominal Dimensions** (m) :
  - A - 8.0 m
  - B - 5.6 m
  - C - 2.2 m
  - D - 5.7 m
  - E - 2.7 m
  - F - 9.6 m

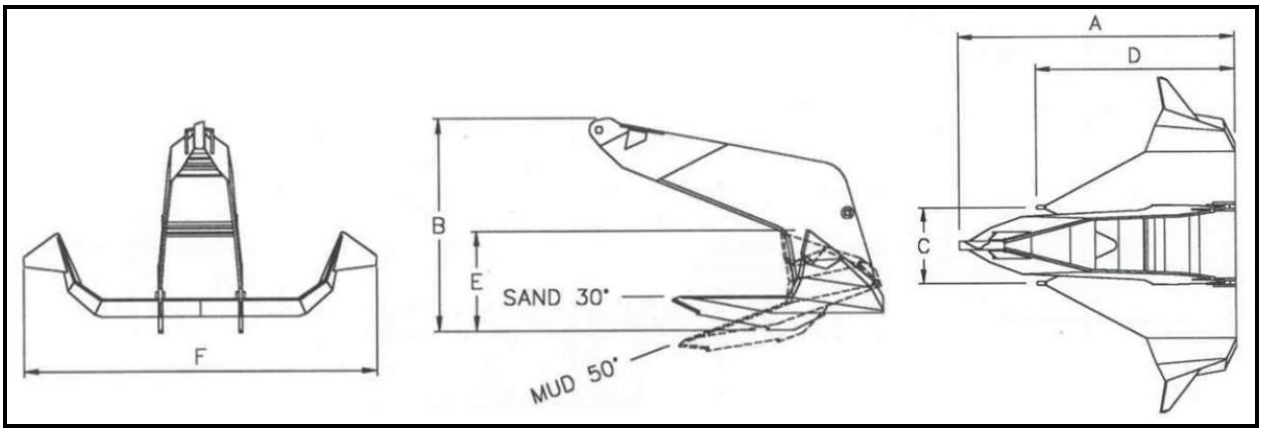


Figure 3-197. Bruce FFTS - MK 4 Seafloor Anchor

A representative Offshore Construction Vessel is shown in Figure 3-198 below. It is a DP-2 Class vessel with a 400-ton mast crane and 100 ton heave compensated winch. It is well suited to support installation of the platform, and anchors. With installation of a portable carousel, it is capable of installation of the power cable and mooring lines as well. If smaller anchors are

selected to for the Pilot Phase, then it is feasible to consider smaller and more available offshore construction vessels with crane capacities in the 200-300 mT range.

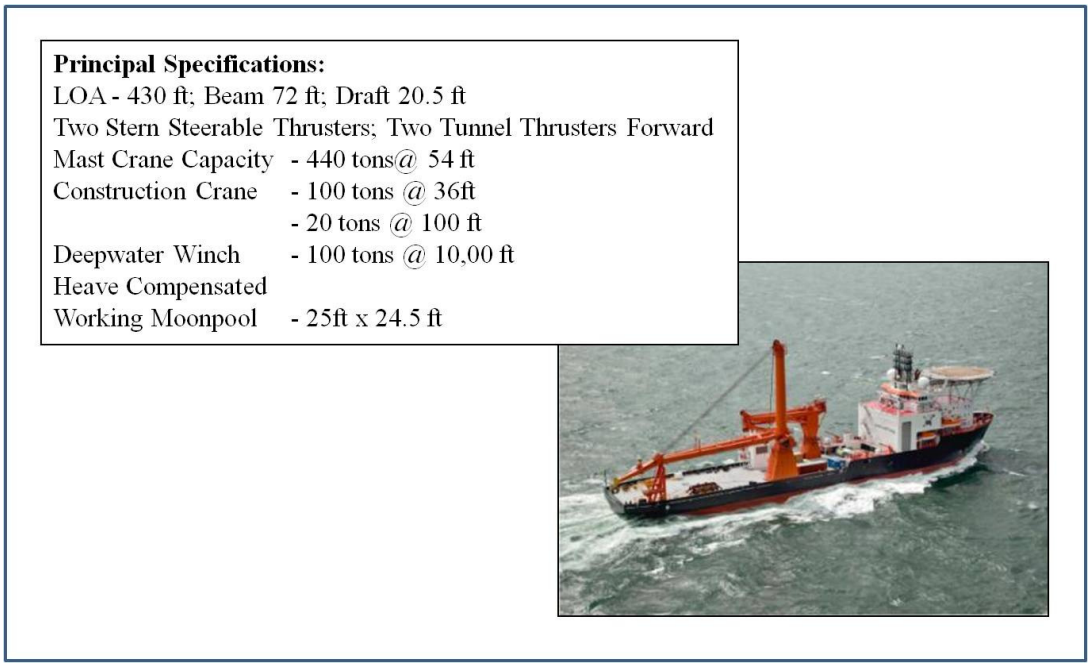


Figure 3-198. Hornbeck Offshore Services Iron Horse – Dynamic Postioning Offshore Construction Vessel

Platform Installation Sequence: The platform installation sequence starts with a tow-out of the platform with anchor handling tugs. See Figure 3-199. Tugs in the 4000-7000 Brake Horsepower (BHP) range will meet this requirement for the OTEC Pilot Plant.

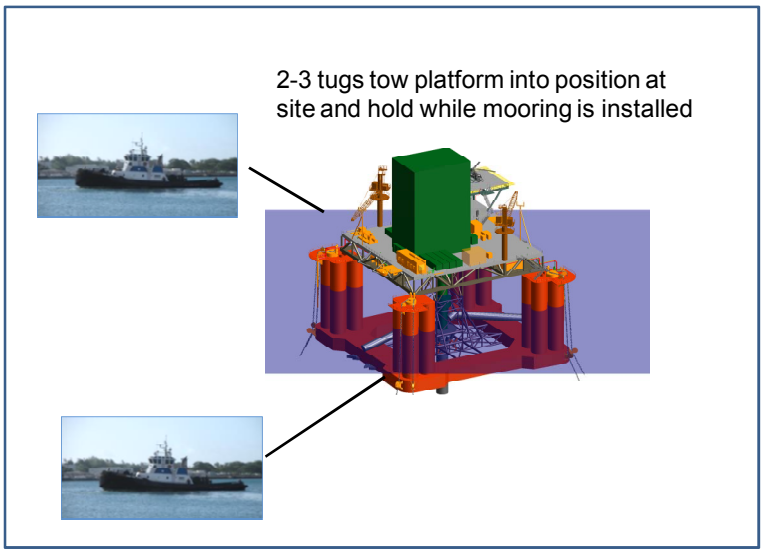


Figure 3-199. Tow Out and Hold

Following tow-out of the platform, the anchors are installed and proof tested. This process is shown in Figure 3-200 and summarized below.

- Anchor Handling Vessel (AHV) transits to mooring area with anchors and mooring components
- Anchors are lowered to seafloor using anchor handling vessel's crane and are tracked using transponders
- AHV hands off the end to platform for subsequent tensioning and proof loading
- Vessel repeats process for anchor on opposite corner of platform
- Anchors are proof loaded using tensioning procedure
- Process is repeated for all anchors until all have been installed and proof tested

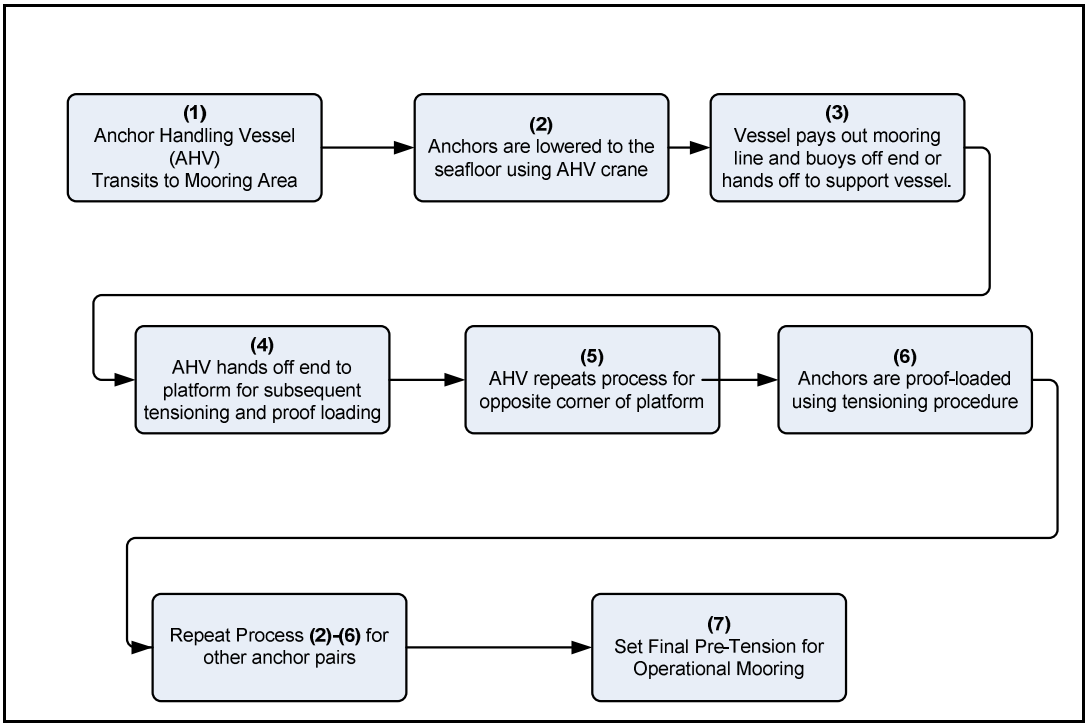


Figure 3-200. Anchor Installation Sequence

Figure 3-201 illustrates the anchor installation process pictorially. Figure 3-202 illustrates the proof-load process using the platform windlass system on opposite corners to apply the proof load tension.

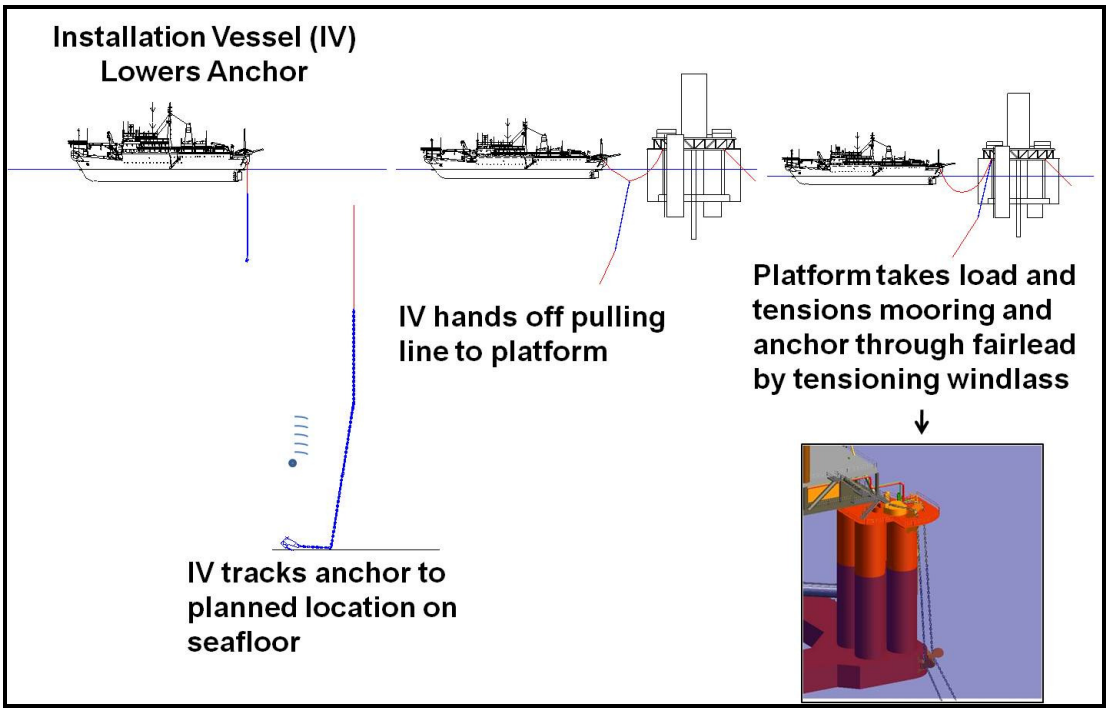


Figure 3-201. Anchor Install and Hookup Sequence

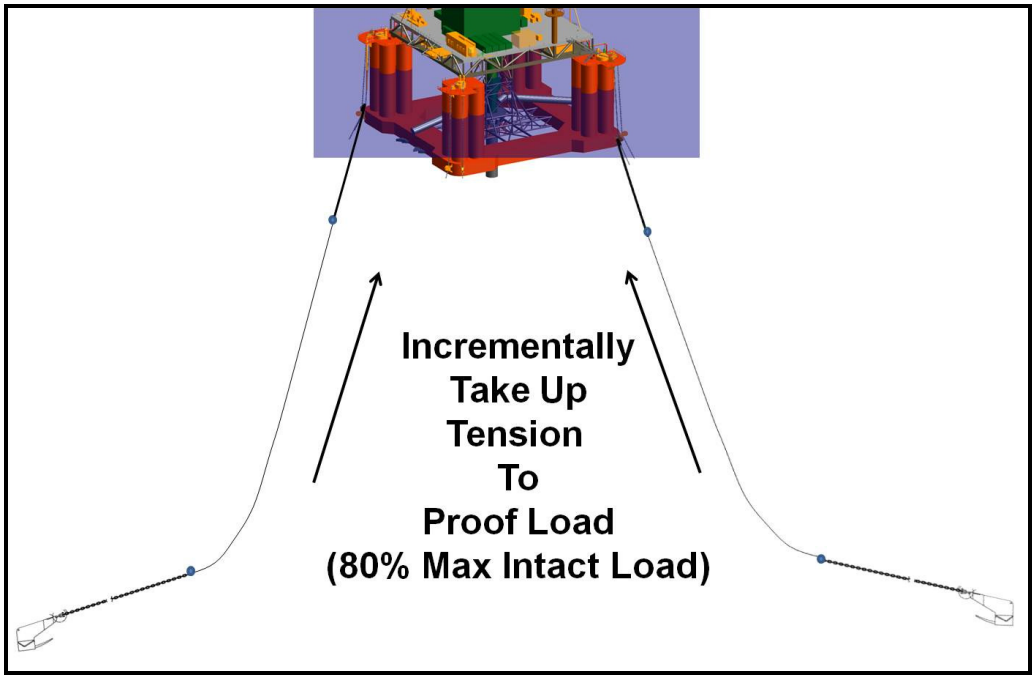


Figure 3-202. Cross- Corner Anchor Proof Loading

Anchor Proof Load Testing

This process assumes that the tensioner capacities and platform structure have rated strength to pretension up to pilot plant proof requirements eliminating the need for additional vessels, tensioning equipment and cost. If this is not the case, then a special proof-loading sequence would be required with an AHV with sufficient winch tensioning capability to pull two anchors against each other with vertical pull. The anchor proof load requirements are established by ABS as 80% of the maximum intact load. For the eight-wire Pilot Phase that tension is estimated at 1179 kN. For the pilot phase this represents a safety factor of 2.91. Even for the production phase, the required proof load is 3663 kN. The corner windlass system illustrated in Figure 3-203 has been nominally sized to a rating of 3557 kN or 30% of the MBL of the chain. So for a slightly (3%) larger windlass the platform tensioning system could be used to proof load the anchors to the higher load rating associated with the 100 year storm condition. The cost of this additional installed capacity will be more than offset by the reduced anchor installation costs.

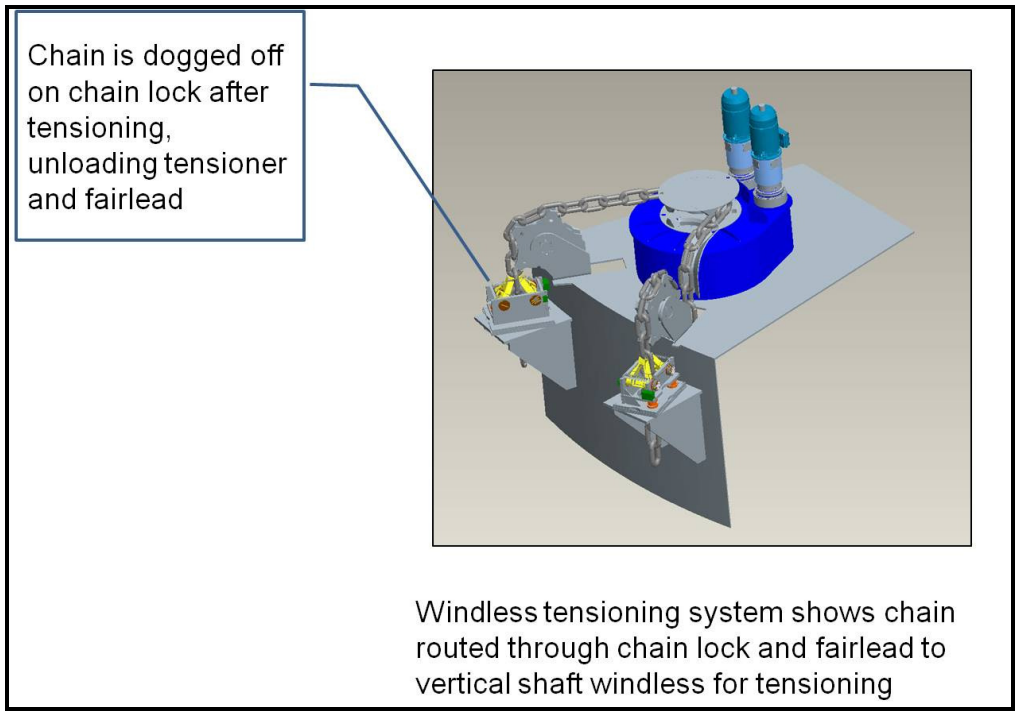


Figure 3-203. Corner Windlass Tensioning System

Platform/Mooring Installation: Forward Plan / Next Steps

The majority of the forward plan for the platform installation involves detailed planning when specifics of the manufacturing locations, mooring configurations, OTEC plant location, and shore landing sites are finalized. These steps are summarized in Table 3-87 below.

Table 3-87. Platform Installation - Forward Plan and Next Steps

Plan	Phase
Detailed design of platform and seafloor interfaces for power cable and subsequent installation CONOPS	Front End Engineering Design (FEED)
Detailed design of mooring and tensioning assemblies and subsequent installation CONOPS	FEED

3.6.2 Power Generation Installation Segment (D2000)

The Power Generation Installation segment covers the transport and installation of the heat exchanger units for the OTEC pilot plant project. The large heat exchangers named remoras are cylindrical vessels 90m long and 15m in diameter with a current weight estimated at 3400 tonnes as shown in Figure 3-204. The power generation installation process uses tugs to move the Remoras from dockside to the semisubmersible platform offshore. Once onsite the Remoras are moved from a horizontal towing position to a vertical position by ballasting/flooding an internal soft tank compartment. The remoras have four watertight bulkheads that run the entire length. Ballast tank number 1 is used for moving the remora from dry-dock to the platform offshore during ocean transport operations. Ballast tank number 2 is used during mating operations to adjust draft as the remora is pulled into the platform and attached. The soft tank is used for upending operations to move the remora from the horizontal towing position to the upright mating/attachment position. Refer to Figure 3-205 for a summary of ballasting provisions.

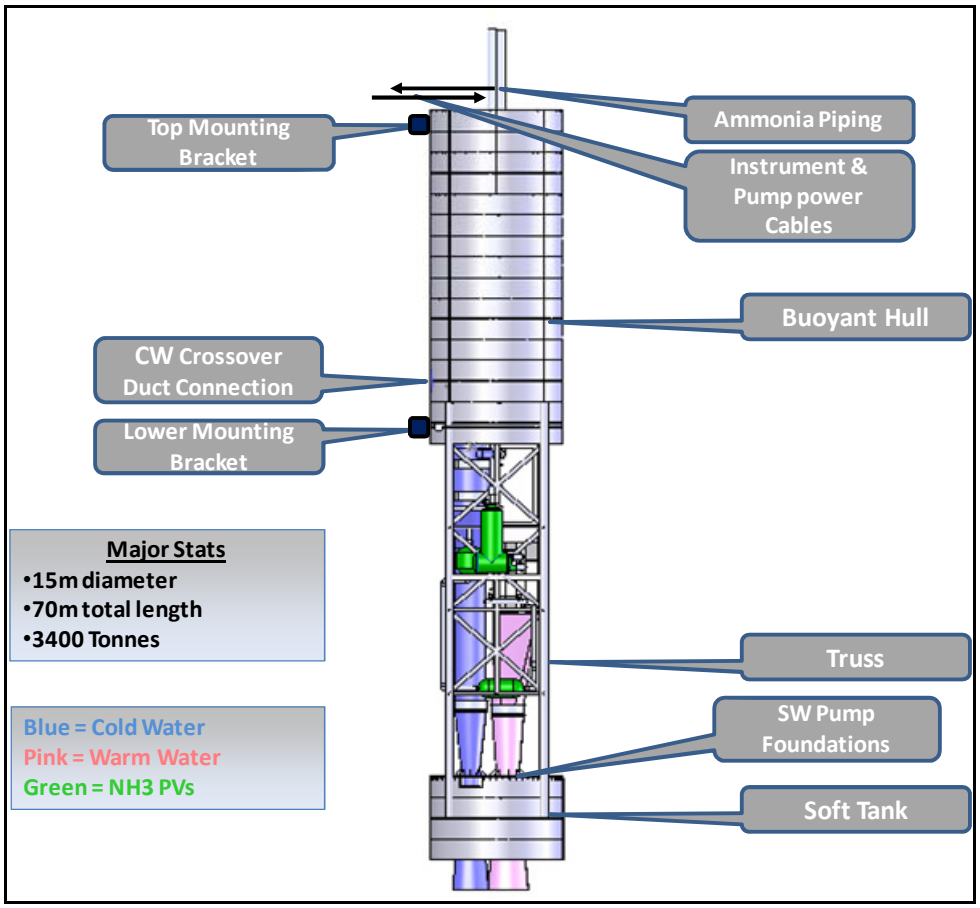


Figure 3-204. Power Generation Subsystem (Remora) - Physical Dimensions

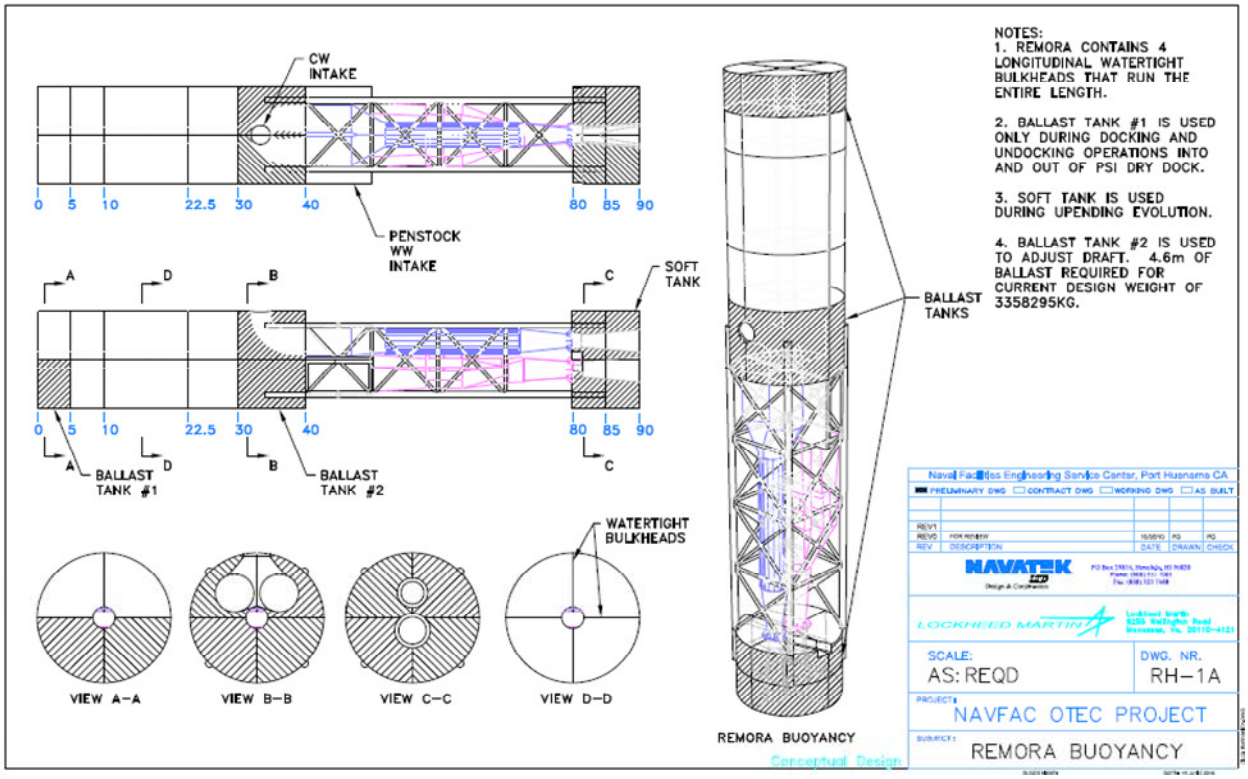


Figure 3-205. Remora Ballasting Provisions

Power Generation Installation Requirements:

The driving Remora Installation requirements are summarized in Table 3-88. The resulting impacts on the Remora installation operation include:

- Installation occurs in light wind conditions and seas as may be predicted based on hindcast results shown in the Design Basis document by J. Halkyard for the Barber Pt area off Oahu
- Remora mating/demating procedure to occur nominally every 3-5 years for refurbishment.
- Remora will be towed from port to platform position deballasted in a horizontal configuration. This may take 4-5 hours to transport depending on port used.
- Remora will be upended by ballasting once on site (2-4 hr estimate)
- Remora will be ballasted so that bottom is tilted forward slightly for mating process, allowing bottom latch to be mated first, followed by top connection at platform deck. This will facilitate a more controlled installation sequence.
- Pull wire(s) from platform will be used to pull remora toward mating latch while a tug will be used to pull back slightly keeping the remora motion controlled as it is mated

- Once mated, the remora will be ballasted further to eliminate any uplift forces on the latching Mechanism. With our current weight estimate, Ballast Tank #2 has +/- 600 tonnes of adjustable ballast capacity. If needed, it can be deballasted as needed if the remora weight should increase due to accumulated external biological growth or other circumstances.

Table 3-88. Power Generation Installation Requirements

Requirement	Source	Rationale	Impact
Remora to be removed and installed at-sea and mated with a moored platform.	Derived system requirements, OTEC Design Basis	Flexible maintenance in dry-dock facility. Power Generation modules replaced quickly. Maximizes system availability	Remora designed for both towed (horizontal) and installed (vertical) configurations.
Remoras installed at sea with 4-hour (nominal) installation and latch-up time line	Derived Requirement	Minimize window for maximum operations flexibility.	Platform and Remora mating and latching provisions. Support vessel capability
Remora installation and latching operations minimize risk to remora, platform, and personnel.	Regulatory provisions for safe at-sea operations	Potentially large dynamic forces and impact loads when mating two independent floating structures	Design provisions for controlling Remora position and orientation during installation. Seas State and other environmental limits for installation.

Remora Installation: Design Decisions / Trade Studies

The main trade analyzed for Remora Installation was using the available tugs to move the remora into position versus pulling the remora onto the platform using wire lines positioned on the platform itself. The decision was made to still use tugs extensively in the process but to also use wire lines from the platform to pull the remoras into the latch mechanism. This approach was considered to provide the best control for mating the large cylindrical remora vessel to the platform while at sea.

Remora Installation - Operations Process: The remoras will be towed partially submerged and in a horizontal position from the port area to the platform site which may be a 4 to 5 hour transport depending on which port is used. Refer to Figure 3-206. Once the remora arrives at the platform

site it will be positioned by ballasting to an upright position. Refer to Figure 3-207. A bridle will be attached to the platform pulling line and the tug will hold back tension as the remora is slowly pulled into position. Note that underwater cameras will be preinstalled on the platform near the underwater mating socket as well as at the topside socket in order to monitor the mating sequence real time as the remora is pulled into position and mated. The cameras will be routed to a display located topsides and will be positioned so that the approach and final mating may be monitored and verified. These cameras may be removed at a later time by divers but should be reinstalled before each mating process.

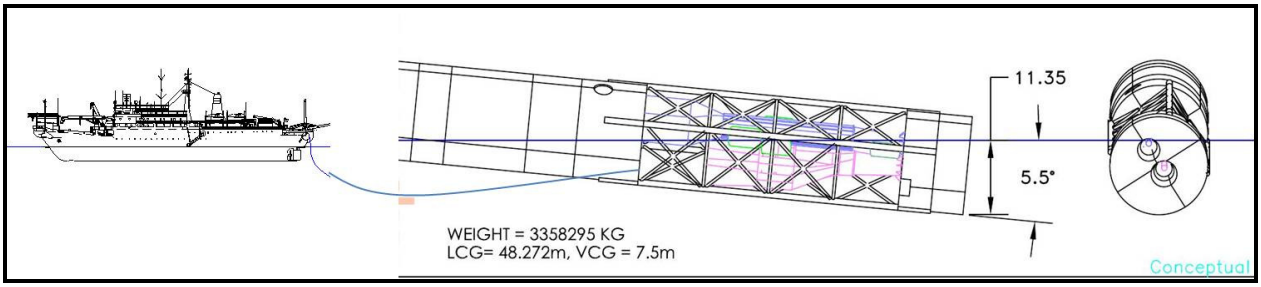


Figure 3-206. Remora Tow Out

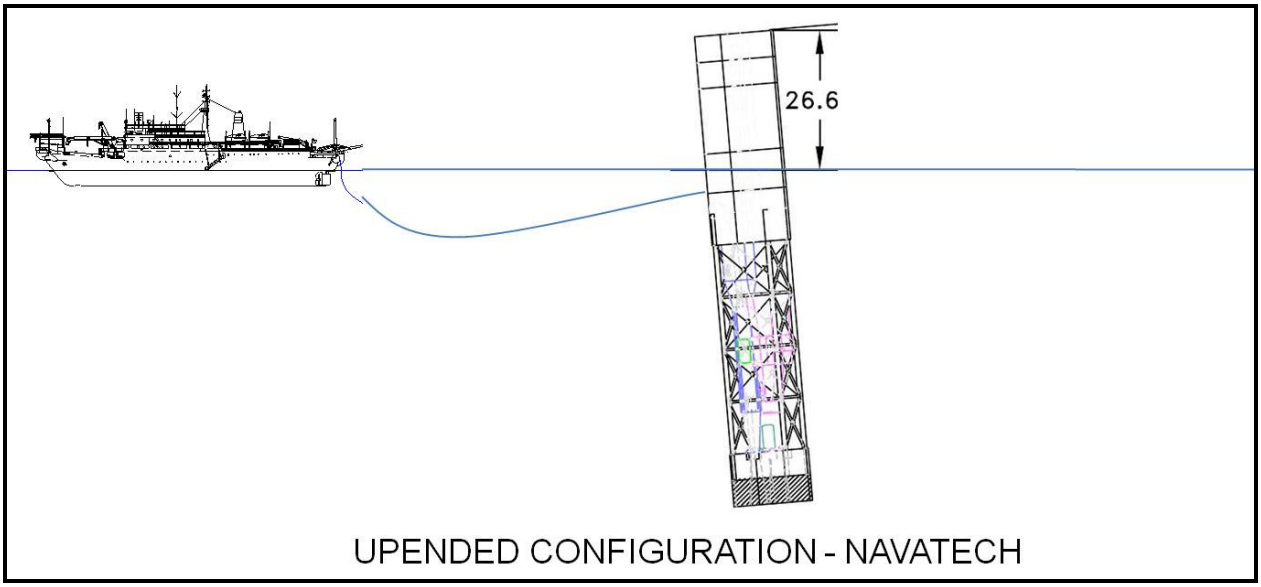


Figure 3-207. Remora Ballasted into Vertical Position

The remora configuration will be tilted back at the top slightly allowing the bottom to contact first at the pontoon level. The bottom is mated first using a gate latch type mechanism and removing all relative motion between the two assemblies. The top is attached at the deck level with a pin in socket arrangement while also deflating bumpers as necessary. See Figure 3-208. The remora is also connected (Figure 3-209) to the CWP interface ducting during this operation, as the mating bar is pulled into the latch on the platform pontoon the CWP interface must also be aligned. The latch design by Navatek is being evaluated further. If the risk is too great during

line pull operations for a misalignment then a diver installed spool piece may be used during this operation. See Figure 3-210. For analysis a 1.25m @ 7.5 second wave was used for relative motion and loads during mating.

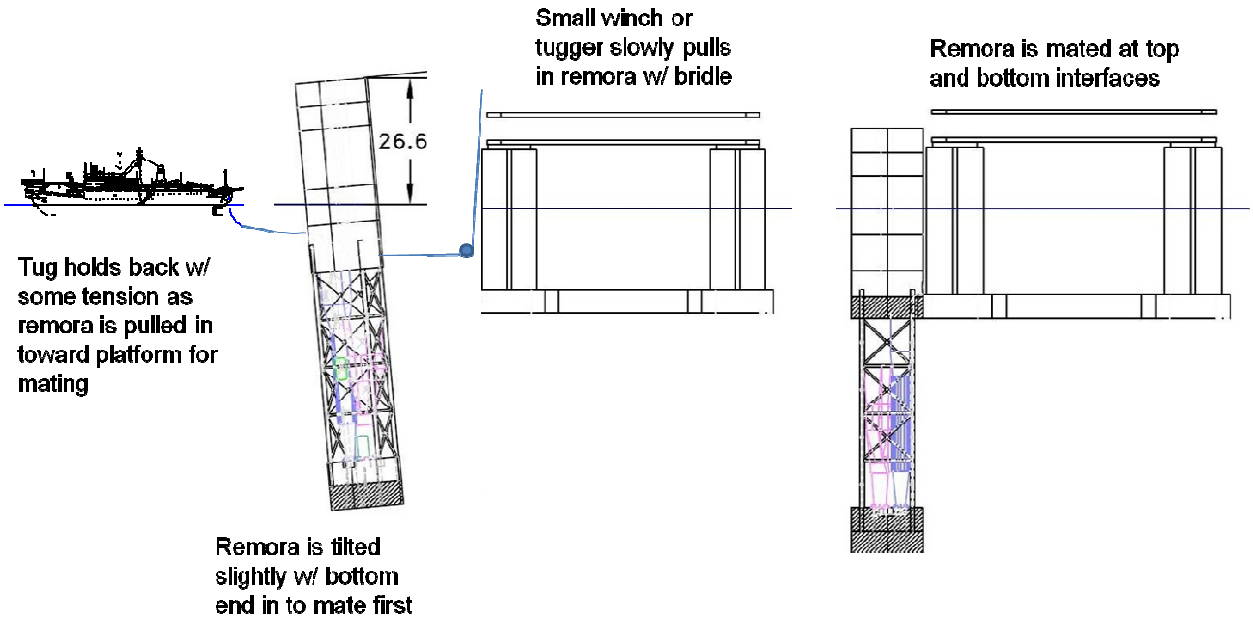


Figure 3-208. Remora Mating Operation

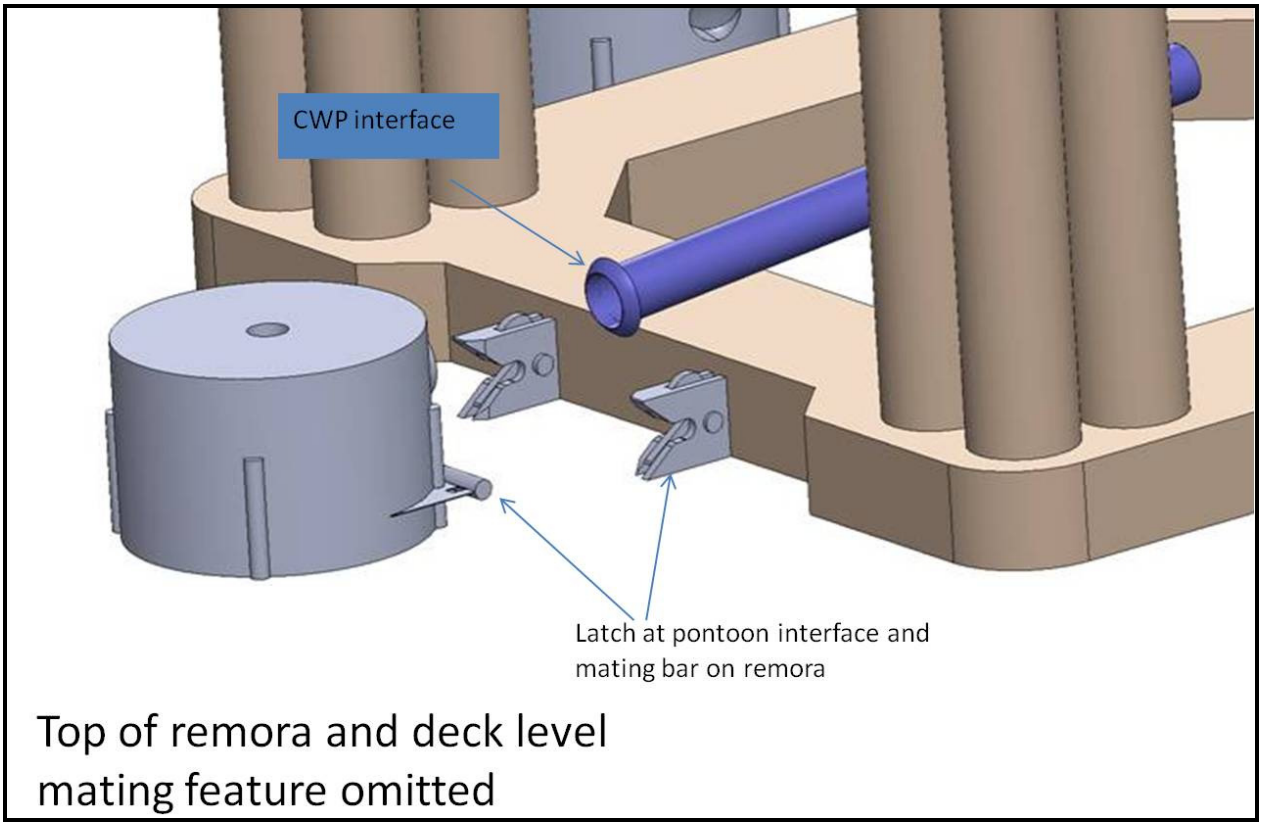


Figure 3-209. Remora Mating Features

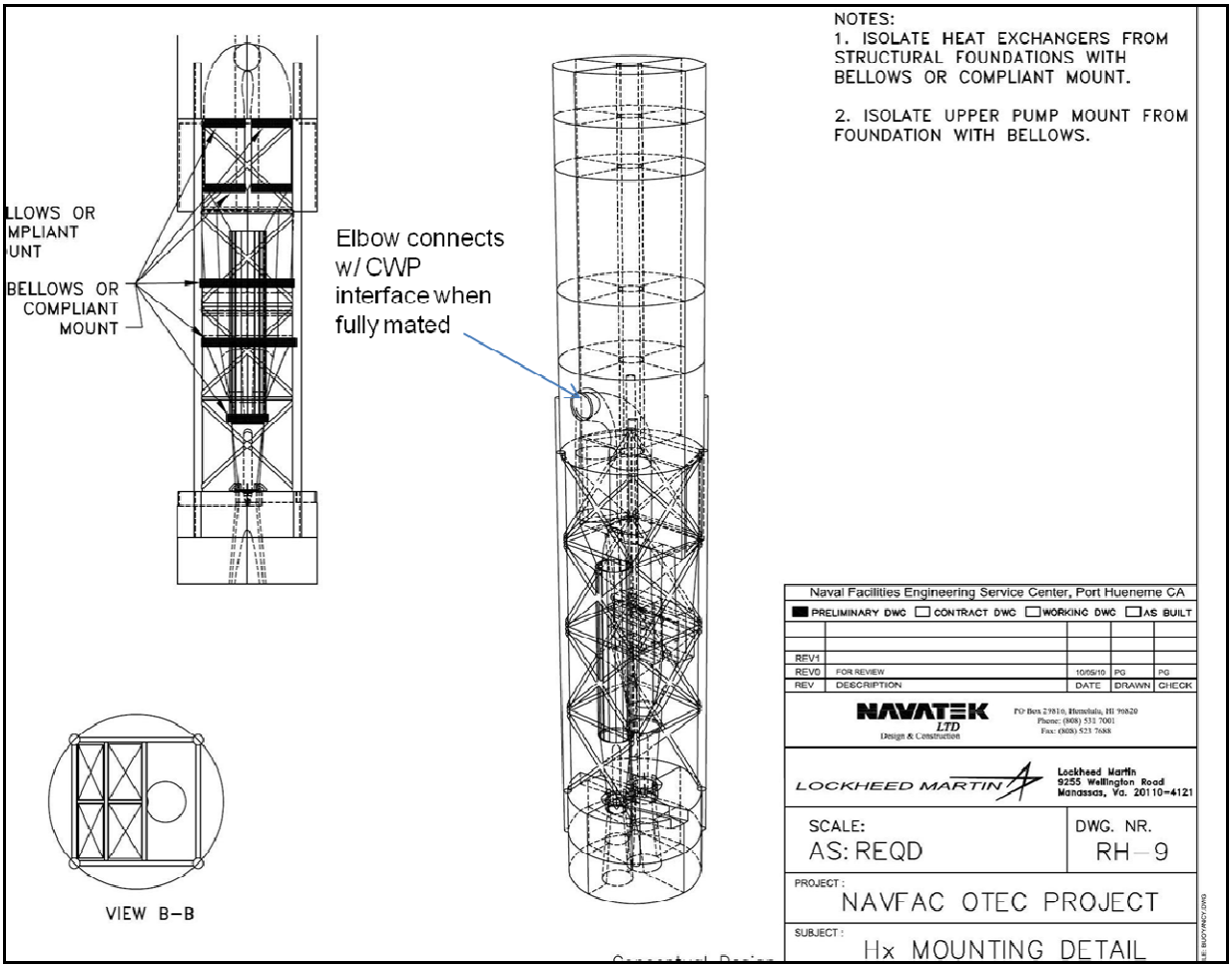


Figure 3-210. Remora Interface -CWP

Remora Installation Challenges:

Remora Draft level: After the Remora is upended it is pulled into the platform with pulling lines, the draft level of the Remora is crucial for alignment and mating of the latch bar to the pontoon receiving mechanism.

Relative Motion: The potential for relative motion between the remora and the platform are a potential risk for successful mating/attachment. The attachment operation is currently required to take place in calm seas, and in the event of rough seas the operation would need to be aborted. A waiting period would ensue until weather permitted another attempt.

Remora Installation - Forward Plans and Next Steps:

The forward plans for the completion of the Remora installation process include:

Latching Mechanism: The latch system for connecting the remora to the platform needs further development. Navatek is continuing a detailed analysis and design of the Remora latching mechanism working on sizing mating components based on anticipated seas.

Ballasting: A detailed ballasting system design for the remoras should be included in the next steps along with a detailed plan/procedure for ballasting and equipment and personnel requirements.

Mating/Attachment: A detailed attachment procedure for the remora to the platform needs to be addressed including wire attachment points and step by step process. This should also include the details of the ballasting procedure.

3.6.3 Cold Water Pipe Installation Segment (D3000)

Details of the design of the Cold Water Pipe Fabrication System are covered in the companion Technology Development Report delivered as CDRL A002 under this contract.

3.6.4 Power Delivery Installation Segment (D4000)

The Installation sequence for the Power Delivery Segment (Submarine Cable) is based on current JDR 35 kV design and is with the assumption that the cable run is approximately 28km long. The current estimate for in-air weight based on the JDR design is 800-1000 tons, and at this weight the cable will be shipped from the factory in a carousel or tank and will be installed directly from the transport vessel or barge. The lack of sufficient load handling in Hawaii necessitates that the cable not be transferred after it is transported to Hawaii at which point it will be installed from the transport vessel or barge directly.

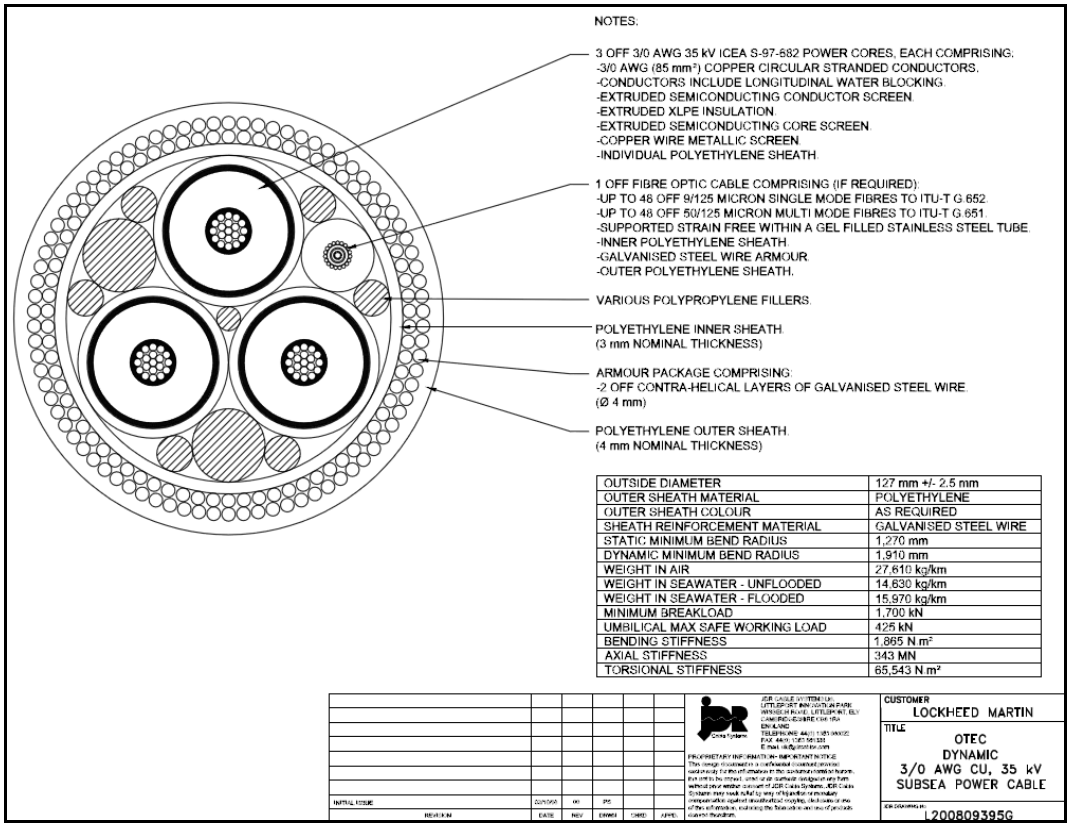


Figure 3-211. OTEC Power Cable

Submarine Cable Installation Sequence Requirements:

The 35Kv cable will be installed and secured on the platform before being laid toward the shore landing site. At the shore station a Horizontal Directional Drilling (HDD) process will be used to complete the cable run. After the HDD operation is completed the cable will be pulled through the bore hole and secured at the shore station before hook-up operations begin.

Design Decisions / Trade Studies

Trade: [Laying Cable from Platform to shore or reverse]

The preferred cable lay sequence is from platform to shore with cable being laid upslope which is a best practice approach for submarine cables. This sequence also allows for both optical and electrical testing of the cable connection during installation as required. The cable will be payed-out using appropriate cable management software such as Makai Lay. The illustration in Figure 3-212 shows a pulling line passed from the platform to the cable ship through the J-Tube. The line is then attached to the cable and pulled back through the J-Tube and the cable is secured to the platform. See Figure 3-213.

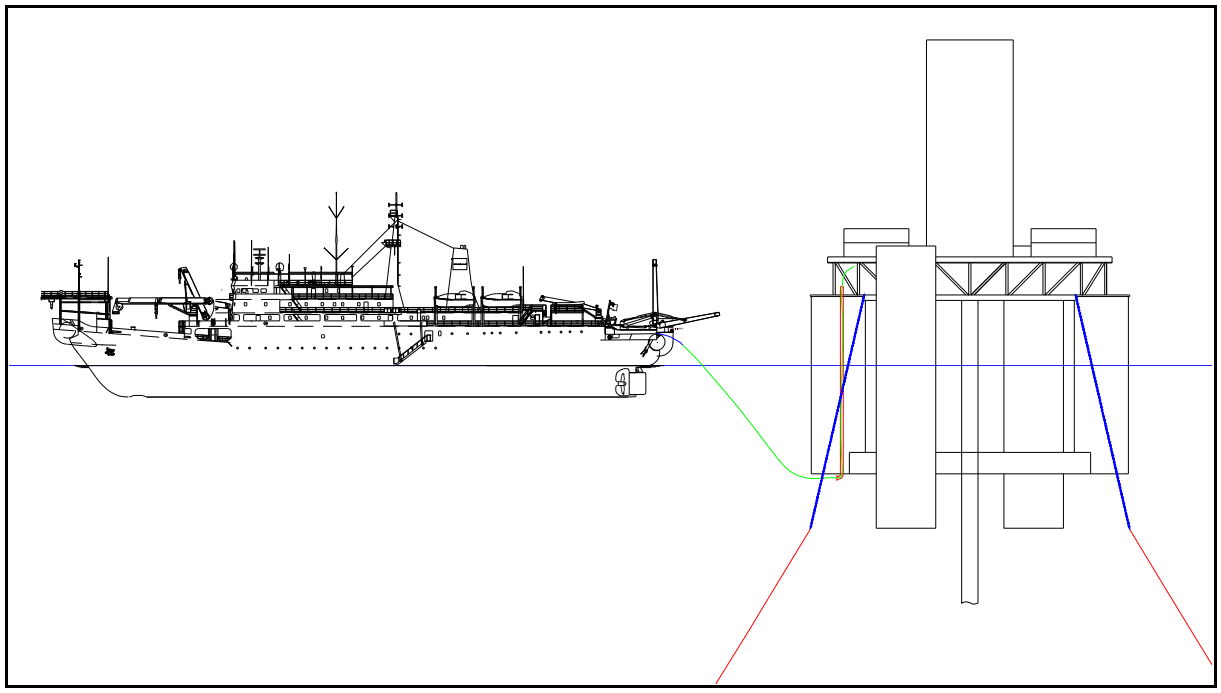


Figure 3-212. Cable Attached to Platform

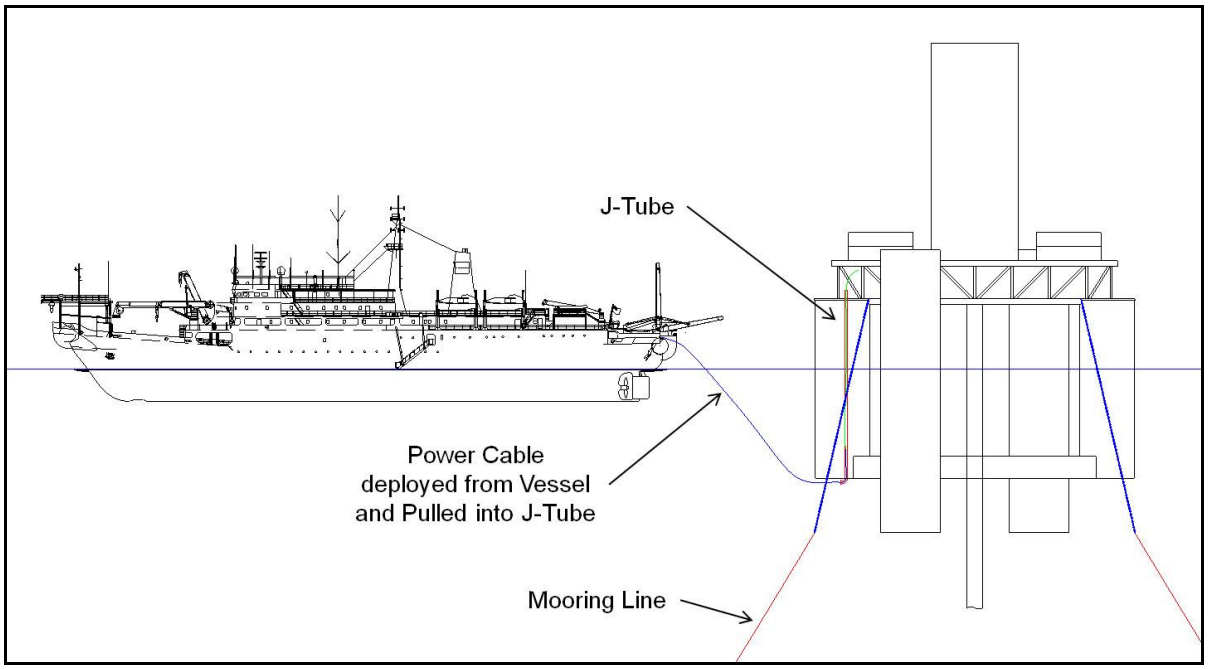


Figure 3-213. Secure Cable to Platform

The vessel continues to deploy cable (Figure 3-214) from the platform down to the seafloor. Distributed Flotation is added for a Lazy-Wave configuration approximately 1000m from the platform and distributed over 250m of cable this allows for the platform to move without exerting a damaging stress into the cable. See Figure 3-214. A seafloor cable anchor is attached to keep the cable from dragging along the bottom and to aide in the deployment to shore.

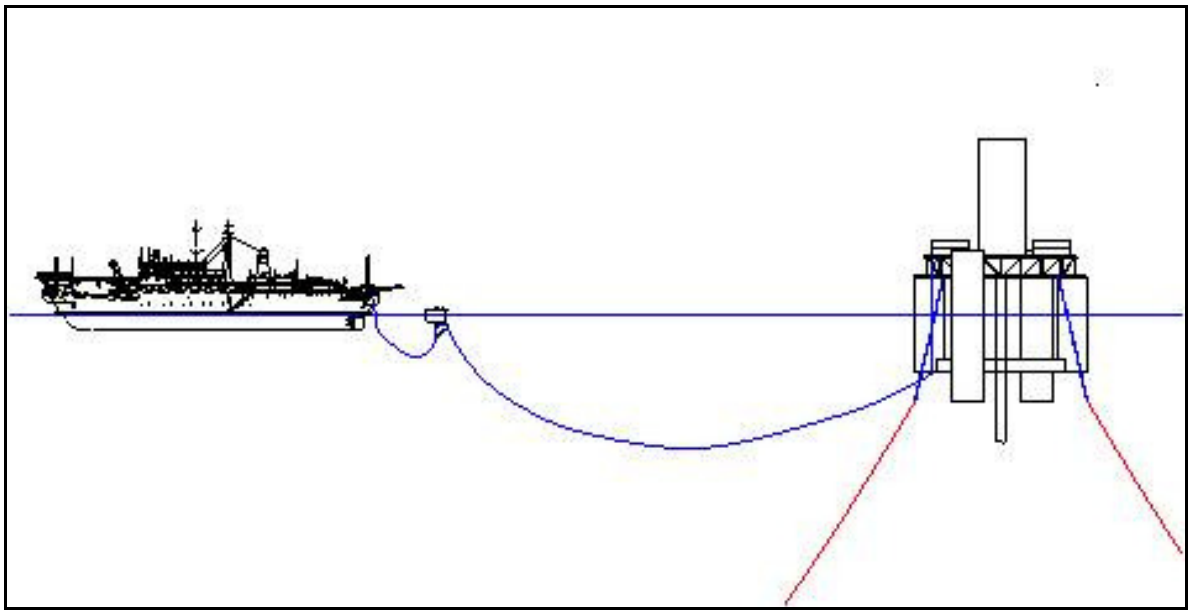


Figure 3-214. Initiate Cable Lay

Trade: (Lazy –Wave or simple catenary design)

A simple catenary for the power cable was determined to be adequate in early OTEC system analysis reports when the maximum platform offset was 67 m. The Pilot Plant design has a broken line condition that results in a potential 148M offset that eliminates the simple catenary design from the options (ref: John Halkyard Technical note TN-10-106). As a result two options for cable configuration were analyzed by Houston Offshore Engineering using the marine dynamics program Orcaflex, the Steep Wave configuration and the Lazy Wave configuration. Results of the analysis showed the Lazy Wave configuration (Figure 3-215) to be the better solution resulting in less tension on the cable during Broken Line conditions as well as a larger minimum bend radius for the cable (ref: HOE Power Cable Configuration Report July 6th 2010).

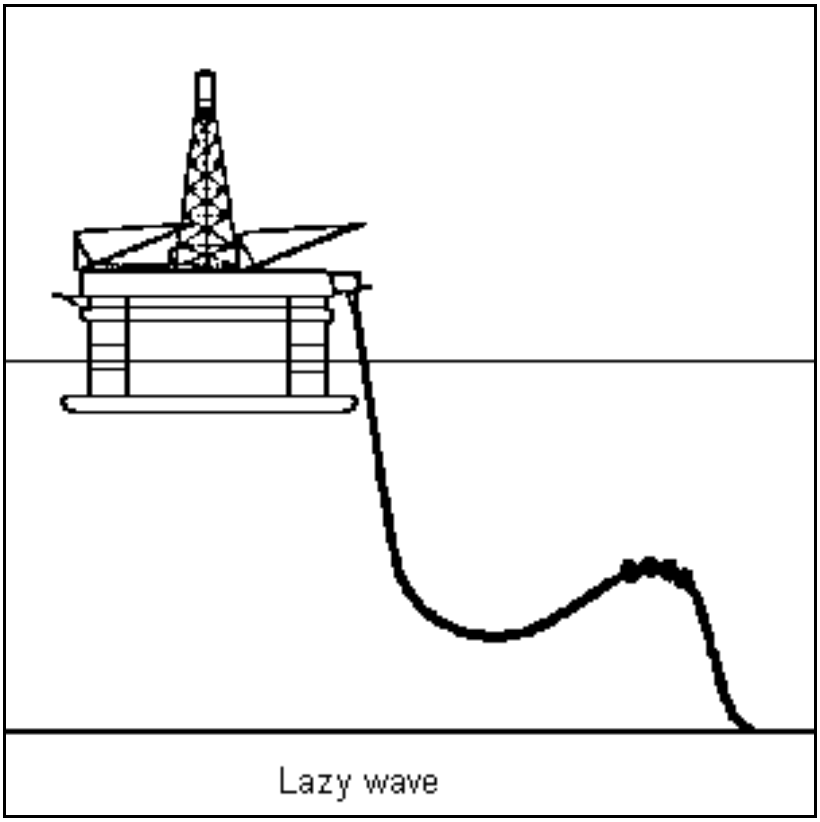


Figure 3-215. Lazy Wave Configuration

Cable Shore Landing

The trade looking at landing the cable over the beach versus using Horizontal Directional Drilling (HDD) resulted in the selection of the HDD approach. This approach avoids damage to the cable and also limits the exposure to air /sea interface where there is potential for abrasion damage from rocks and sand continuously washing over the cable as well as the potential for ultra-violet (UV) damage. The HDD process uses a drill that bores a hole underneath the near shore and intertidal zones. HDD uses a precision-guided directional system to bore a hole through soil and/or rock, the drill bit is steered along a pre-determined path using internal

hydraulics and the computerized guidance system. The drilling equipment is mounted on a platform that can be located on a relatively small area of land (see Figure 3-216). The entire process has a small environmental footprint which is limited to the drill platform site, the borehole, and the drill exit area, with the platform site being a temporary condition during construction. Once the bore hole is completed conduit is placed and the cable can then be pulled up through the hole at the drill exit on the ocean floor. On the ocean side the cable is attached with flotation to maintain it up off the seafloor which helps prevent dragging rock and sediment into the conduit that might result in a plug. The cable has a pre-installed pulling head that a line is secured to, pulling commences and floats are removed as required. All slack is pulled through the conduit and a service loop is installed at the cable vault. Post burial is done on the seafloor cable as required.

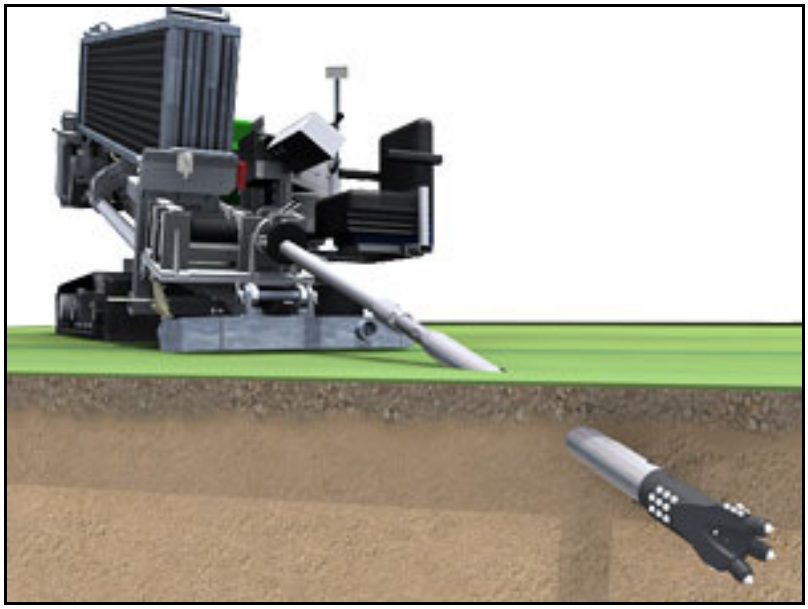


Figure 3-216. Horizontal Directional Drill

Power Delivery Segment (Submarine Cable) - Installation Challenges:

The challenges for cable installation are associated with equipment and the operations process. It's important to select the correct equipment for the project with regard to the site characteristics and cable route and plan. During installation following the planned cable route is important along with following all the planned parameters for the cable lay including the cable path, the slack line amount and the tension on the cable during the laying process. Having the onboard capability to re-terminate the cable in case of failure or damage is an important consideration in vessel selection. All these contributing factors pose a potential risk when planning for a successful cable deployment.

Power Delivery Segment (Submarine Cable) - Forward Plan / Next Steps:

Detailed Interface Design: Detailed design for the interface to the platform for the power cable needs to be conducted as a next step, along with the seafloor interface and cable anchor detailed design. Flotation requirements need to be identified for specific depth, configuration and cable interface.

Cable Shore Landing: A Detailed shore landing plan for HDD (horizontal directional drilling) should be conducted. The plan should include the dead man anchor and location, vault location and details, and the transition to terrestrial cable details.

Dynamic Analysis: A dynamic analysis of Lazy Wave cable configuration should be included with any follow on work associated with the power cable.

Cable Lay Plan: A cable lay plan should be detailed out to optimize the route and select the best path using Makai Lay software.

Emergency release: A power cable emergency release is proposed to be included in future design work that would allow the cable to drop away from the platform to safeguard against cable failure during catastrophic storm conditions.

3.7 OTEC Decommissioning System (E)

It is anticipated that permitting for OTEC plants will include requirements for their removal and site restoration at the end of its economic life. Therefore, preliminary planning and budget allocations have been made for the eventual cost of removing the plant. In the spirit of the active movement toward green shipbuilding and shipbreaking worldwide, there are decisions that can be made during construction that will reduce the non-recyclable waste streams when the OTEC plant becomes inoperable or obsolete. The discussion that follows broadly reflects current environmental regulations and international treaty obligations in the US. The Key Decommissioning Requirements are contained in Table 3-88 below.

Table 3-88. Decommissioning Key Requirements

Requirement	Source	Rationale	Impact
Fiberglass Reinforced Plastic (FRP) pipe shall be removed and disposed of in a secure landfill or by controlled incineration.	regulatory	MARPOL Convention[11]	Additional cost of decommissioning plant if program is abandoned at the end of the demonstration project.
NH3 shall be collected for recycling or disposed of properly.	regulatory	Regulated toxic substance under the Clean Air Act[9] Designated hazardous substance under Clean Water Act[10]	

Requirement	Source	Rationale	Impact
Petroleum, oil and lubricants (POL) shall be collected for recycling or disposed of properly.	regulatory	Marpol (Marine Pollution) Convention, Clean Water Act, and other regulations prohibit the discharge of oil	
All other regulated or hazardous waste streams from potential ship-breaking operations shall be disposed of properly.	derived	Various	

3.7.1 Platform Decommissioning Segment (E1000)

The platform that supports the cold water pipe and on which the OTEC power system resides is a candidate for recycling using conventional shipbreaking techniques. Though not a regulated industry, the International Maritime Organization has issued guidelines on Ship Recycling[8]. Conscientious preparations would involve removing hazardous substances from the vessel before dismantling it, which include:

- Fuels, lubricating, hydraulic, and other oils
- Waste oil
- Coolants, fire suppressants (halon and Aqueous Film Forming Foam (AFFF)), and antifreeze fluids
- Compressed gases
- Residue from tanks and pipes, including potentially invasive species
- Water treatment chemicals
- Anti-fouling (or other) coatings
- Lead-acid batteries, battery electrolyte
- Metal wastes (antimony, beryllium, cadmium, lead, mercury, tellurium)
- Floatable materials (e.g., plastics, Styrofoam insulation)
- Miscellaneous electrical equipment, such as flat screens or cathode-ray tubes

Rotating machinery is a candidate for reuse or further dismantling for parts. Insulation, both thermal and electrical, may require special packaging and handling for disposal. Conductors in power cable can be reclaimed. While some electronics may be a candidate for reuse, most of it

[8] International Maritime Organization Resolution 962, IMO Guidelines on Ship Recycling

will enter the electronics recycling stream. The platform itself can be towed to a dismantling yard for breaking and recycling. The scrap value of the platform has been deducted from the estimated expenses.

Decommissioning the mooring system has been assumed to be a zero-cost item, since it may be suitable for abandonment in place. It may also be a candidate for recovery and recycling, or for reuse. Drag embedment anchors, in particular, may be candidates for reuse, while the remainder of the metallics may have scrap value that exceeds the cost of recovery.

3.7.2 Power Generation Decommissioning Segment (E2000)

Decommissioning the power system will involve the proper collection and disposal of the ammonia working fluid. Ammonia is a regulated toxic substance, and may not be casually vented into the atmosphere in large quantities under the Clean Air Act[9]. Ammonia is also highly soluble in water, and has been designated a hazardous substance under the Clean Water Act[10]. The plan assumes that the ammonia systems will be purged, and the ammonia can be collected for its value as a commodity used in refrigeration plants and fertilizer manufacturing.

3.7.3 Cold Water Pipe Decommissioning Segment (E3000)

The decommissioning plan assumes that the fiberglass cold water pipe will be recovered, and sectioned for eventual transport to an upland disposal site. Fiberglass is a plastic, the disposal of which is prohibited at sea under the MARPOL Convention[11]. While the volume of fiberglass waste could be reduced by up to 70% through thermal oxidation (incineration), it is not clear at the time of this writing that it can be done economically. It is anticipated that incineration will have to be highly controlled, and the gaseous products of combustion will have to be subjected to post-treatment. The plan assumes that the gripper system will be reinstalled for the purpose of recovering the cold water pipe.

3.7.4 Power Delivery Decommissioning Segment (E4000)

The plan assumes that the power export cable can be abandoned in place. There is precedent for such abandonment in deep water, and the cost associated therewith is very minor. While the salvage value of copper conductors may make recovery an attractive option, modeling the cost and scrap value of salvaged power transmission cable would be speculative at best and, hence, has not been attempted herein.

[9] Pertinent regulations codified at 40 CFR 68.130, threshold quantity 10,000 pounds

[10] Pertinent regulations codified at 40 CFR 117.3, Reportable quantity 100 pounds

[11] The International Convention for the Prevention of Pollution From Ships, 1973, as modified by the Protocols of 1978 and 1997 relating thereto, Annex V: Prevention of pollution by garbage from ships

4. INTEGRATION & TEST

System Integration and Test Standard Process

System Integration and Test (SI&T) tasks and activities for the OTEC Pilot Plant will be guided by the Lockheed Martin Mission Systems and Sensors (MS2) Standard I&T process. Figure 4-1 (A & B) shows a diagram of the flow of these tasks and activities. Milestone events (kick-off and Test execution) are shaded green, Development activities are blue, Reviews are tan and Work Products are shaded yellow. This process is tailorable to accommodate the needs of the particular Program or Project. Timing is included as a suggestion to aid in planning ("T" represents the Test Event).

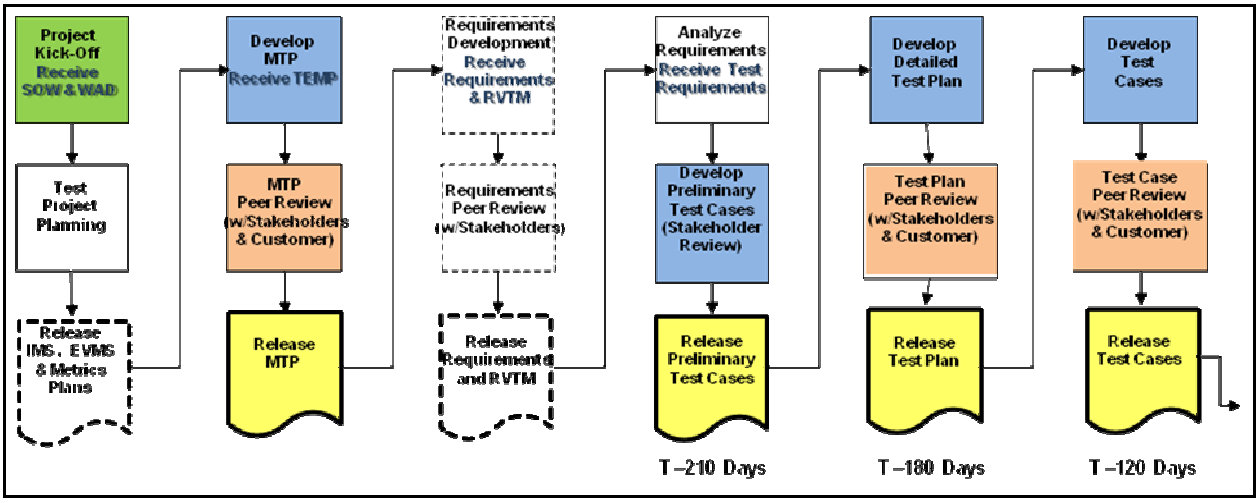


Figure 4-1A. SI&T Process Part 1

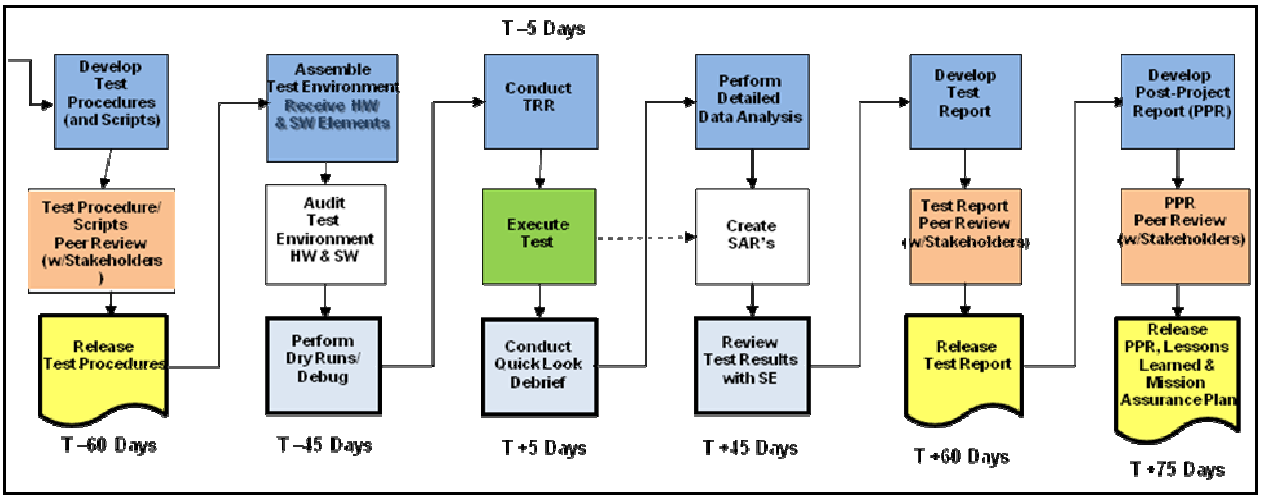


Figure 4-1B. SI&T Process Part 2

4.1 Integration and Test Approach

4.1.1 OTEC Pilot Plant Test Approach

The Test Approach, also referred to as Integration, Verification, and Validation (IV&V), for the OTEC Pilot Plant involves verification of requirements and specifications for each component, assembly, subsystem, element, segment, and the total system as defined by the OTEC Pilot Plant System Logical Architecture Diagram (refer to section 3.1.4 for this diagram).

The OTEC Pilot Plant Test Approach is based largely on the requirements and specifications developed for each level of the system described in the Logical Architecture. The requirements are depicted in the OTEC Pilot Plant Specification Tree (refer to section 3.1.4 for this diagram). A System Physical Architecture has also been developed which describes the breakdown of system components and parts using the Logical Architecture as the framework.

Using this Building Block approach allows the team to focus on performing tests at the appropriate (lowest) levels to achieve the goal of prevention of defects or their early detection and removal as early in the life cycle as possible. Discovery and correction of defects becomes much more costly as each successive development stage is reached. Our guiding philosophy and principles are:

- All "components" will be tested/verified (accepted) prior to integration activities
- Integration activities will precede qualification or acceptance testing of "subsystems"
- No integration or test event or activity will take place in the "shipboard/at sea" environment for the first time. Though this may not always be feasible, our goal is to integrate and verify each component, subsystem, element, segment, and system prior to the System Integration and Test Phases.
- Integration, Verification and Validation (IV&V) activities

Integration, Verification and Validation activities will be defined as follows:

a. Integration

   As the lowest level components are verified, they will be integrated at the next higher level in the architecture hierarchy, followed by more formal verification or qualification testing. This process will proceed until the entire system has been assembled, integrated, and verified/tested. Integration activities ensure that the subsystem/system conforms to the Interface Requirements.

b. Verification

   Verification activities may take the form of supplier or vendor testing and certifications (e.g. Factory Acceptance Tests). In some cases engineering evaluation or development testing may be necessary in order to assess product performance and the suitability of our design (e.g. Qualification and Acceptance Events). Verification activities ensure that the product meets the stated requirements /specifications.

c. Validation

The System Engineering, Integration and Test (SEI&T) team in consultation with external customers designate key integration and test activities to be validation events that will be witnessed and signed off by external customers as complete. These events will be scheduled throughout the engineering life cycle not just at the end as has been the former practice. As major subsystems or elements are integrated and tested validation activities will be scheduled. Candidates will be, for example, the At Sea Fabrication of test lengths of Cold Water Pipe, Turbine-Generator I&T, Heat Exchanger (Condenser and Evaporator) I&T, Remora I&T, Platform I&T, Integrated Instrumentation and Control Electronics and Software I&T, Onshore Substation I&C, and Power transmission Cabling and support equipment I&T. Validation activities ensure that the product meets the Customer/Stakeholder expectations (e.g. CONOPS, Mission Objectives, etc.) (System Operability Events).

All of these types of activities are captured in the OTEC Pilot Plant Master Test Plan Draft which identifies the testing to be performed so that all aspects of the system are adequately integrated and verified and validated to ensure successful system implementation. A Test Flow Diagram gives a visual representation of the flow of these tests and will be discussed further in section 4.2 Integration and Test Flow.

4.1.1.1 Integration Verification &Validation Levels of Testing

The IV&V Program consists of several levels of testing to include both informal (not officially witnessed and signed-off) and formal (officially witnessed and signed-off) activities and events as follows:

- Engineering Development Testing

  Generally, these are informal activities such as Engineering Evaluations/ Tests or Design Verification Test (DVT) which are used to assess and evaluate concepts and collect performance information.

- Factory Acceptance Tests (FAT) [Verification]

  These tests may be informal (accomplished by the vendor or supplier) or formal (performed and witnessed for record) and include Acceptance Tests and Vendor or Subcontractor Certifications or Certificates of Conformance.

- Environmental Qualification Tests (EQT) [Verification]

  Generally these tests are comprised of informal or formal events conducted as the system design changes and matures and include Temperature, Humidity, Shock, Vibration, Salt Spray, Hail & Rain, Electro-magnetic Interference (EMI), Electro-magnetic Conductance (EMC), Electro-Magnetic Pulse (EMP), and similar tests. The requirements for these conditions are often tagged or segregated from the other requirements.

- Formal Qualification Test (FQT) [Verification]

  These tests are usually officially witnessed tests conducted for Configuration Items (CIs) for Hardware, Software, or Firmware components or subsystems.

- System Integration (SI) [Verification]

  These are system level activities conducted for the purpose of interface verification. This involves connecting/ integrating accepted components of a subsystem, element or segment together to ensure they interface and "communicate" properly in accordance with their respective interface requirements.

- System Integration and Test (SI&T) [Verification]

  These are system level tests conducted for the purpose of verifying a subsystem, element or segment meets its system level requirements (lower level requirements having been verified in earlier testing). These tests may be combined with integration activities when feasible or desirable.

- System Operational/Operability Test (SOT) [Validation]

  These are system level tests conducted for the purpose of verifying that the system operates in accordance not only with its system level requirements but also its System Operational and Functional scenarios developed from the System Concept of Operations (CONOPS) and Mission Objectives.

4.1.1.2 IV&V Work Products/Artifacts

Our System Integration & Test process yields a number or work products developed based on Specifications, Requirements and Detailed Designs that culminate in the following test documents:

- Integration or Test Plans

  Test Plans are developed from preliminary or draft requirements and specifications and are the basis and framework for the Test Cases. Each detailed Test Plan contains information for each test/event to include; Test Objective, Test Description, Special Requirements, Cross Reference to Requirements, Data to be Recorded, Assumptions and Constraints, Prerequisites/Entry Criteria, Test Schedule & Location, Test Configuration, Test Resources, Test Documentation, and Success (Exit) Criteria. It should also describe the test environment (facilities, tools and equipment) that will be needed.

- Integration or Test Cases

  Test Cases are developed for each requirement or set of requirements and are the basis along with design documents and drawings for development of the Test Procedures. The major Stakeholder review is held to reach agreement that all requirements are being properly and completely verified to everyone's satisfaction.

- Integration or Test Procedures and Scripts/Drivers

  Test Procedures and Test Scripts are developed from the Test Cases and Design Documentation.

- Integration or Test Reports

  Test Reports capture the observations and results of the Test Event. Several work products are a part of the report; Test Run Log, Test Article and Equipment Audits, Collected Test Data, Analyzed Test Data, Trouble Reports that describe defects, and As Run Test Procedures and Scripts. A summary of the results and a recommendation to perform retesting or proceed is also included.

4.1.2 OTEC Pilot Plant Test Documentation

4.1.2.1 OTEC Pilot Plant Master Test Plan (MTP) Draft

The OTEC Pilot Plant Master Test Plan (MTP) Draft describes the entire Integration and Test (i.e. the Integration, Verification and Validation [IV&V]) Program which encompasses Engineering Development through System Verification and Validation for the development and deployment of the Plant. The Integration activities formerly described in a System Integration Plan (SIP) and the Test (Verification and Validation) activities are combined into the MTP. Special test equipment will be developed (simulators and data acquisition equipment) in order to create the necessary test environment for each test activity. Special and Standard test equipment are identified in the MTP and in each detailed test plan. A listing of these tests can be found in section 4.2.2 List of Planned Tests. There are approximately 150 test identified thus far.

The OTEC Pilot Plant Master Test Plan Draft is located in Appendix 4.1-1 of this document.

4.1.2.2 OTEC Pilot Plant System Integration Test Plan Draft

The OTEC Pilot Plant System Integration and Test Plan Draft describes in greater detail than the MTP the system assembly integration and checkout activities that are planned to occur in three Integration and Checkout/Test (INCO) Phases (approximately 202 tests). The three phases are summarized as:

- Phase 1 – Shipyard INCO - Shipyard/Builder's Site Integration and Test (~64 tests) and includes:
  - Platform construction & installed equipment INCO
- Phase 2 – Quay-Side (in Hawaii) Integration and Test (~42 tests) and includes:
  - CWP Fabrication System installation (Apparatus, Environmental Enclosure & Gripper/Handler)
  - Remora Testing in the Horizontal attitude to the extent feasible
- Phase 3 – At Sea/Deployed Site INCO and Acceptance (~96 tests) and includes:
  - Platform Mooring & Anchoring installation and test
  - Remora installation and test
  - CWP Fabrication System tests and operation
  - Power Transmission Cabling installation, connection and test

Shipyard Integration and Test (INCO) at Builder's Site

The first phase will take place at the platform builder's site and will involve construction of the platform and installation of major equipments that are integral to the platform. This will include standard platform electrical, communication & control, outfitting, furnishings and auxiliary equipments. Additionally, OTEC specific equipment will be installed and checked out including the cold water manifold and ducting, Turbine-Generator, Ammonia Charging and Storage, Integrated Instrumentation and Control electronics, and provisions for installing, mounting, and attaching other OTEC specific equipment at future times. Prior to arrival at this site individual equipment may also have been assembled and tested at Land-Based integration and test sites.

Quay-Side (in Hawaii) Integration and Test

The second phase is to be performed quay-side at a staging and assembly facility/ site outfitted for this purpose near the Plant selected site near Pearl Harbor in Oahu, HI. In this phase, the platform with its installed equipment will be relocated and additional Platform subsystems, elements and segment will be installed, integrated, and tested. The Remora will be floated alongside the platform in a horizontal orientation and connected to the platform for limited integration and testing with the Turbine-Generator Element and warm and cold seawater sources. Any additional Cold Water Pipe Fabrication System segments or elements will be installed and checked out. The Platform and onshore substations will be outfitted, integrated and tested possibly at this stage or during the next.

At Sea/Deployed Site INCO (Integration and Test) and Acceptance

The third phase will take place "at sea" at the selected site for the Pilot Plant off Barbour's Point near Pearl Harbor, HI. The Platform and installed equipment will be towed to the site and attached to the mooring subsystem that will have already been installed and checked out. The Platform will be anchored, the Cold Water Pipe fabrication materials delivered, and the pipe fabricated and deployed. Deployment of the CWP involves installation of the termination and attachment and interfacing to the platform and CW pre-installed ducting. The Remora will be towed to the site in a horizontal orientation and then upended for attachment to the platform, installed, integrated and tested. The Power transmission cabling and support equipment will be installed and checked out and the Platform Substation will be integrated with the On-shore substation and tested. Any additional Platform equipment will be installed, integrated and tested. At the end of this System Integration and Testing phase the Pilot Plant will be ready for System Acceptance testing. The OTEC Pilot Plant System Integration Test Plan Draft is located in Appendix 4.1-2 of this document.

Thereafter, the Pilot Plant system will be connected to the grid as described in the Pilot Plant to Grid Interface Test Plan. Another Validation event may also be scheduled at this juncture.

The final stage will be operational evaluation for the 2 years of the Pilot Plant Pilot Test Phase. These activities and measurements and analyses will be described in an operational test plan.

4.1.2.3 OTEC Pilot Plant Grid Interface Test Plan Draft

The OTEC Pilot Plant Grid Interface Test Plan Draft describes the connection and testing of the Pilot Plant to the Local Grid System. There are approximately 21 test identified for this event which will comprise two stages:

- Testing of the Pilot Plant in a stand-alone condition prior to making any Grid connections
- Testing of the Pilot Plant once connected to the Grid performed in a step-wise fashion

Each stage/phase is divided into the following sections for system testing:

- Start-Up (bringing each piece of equipment on line)
- System Operation (all equipment operating in a normal mode)
- Safety System Tests (verifying and validating that all safety systems operate effectively as expected)
- Automated Test Equipment (ATE) checkout (Self-Test) (automatic detection and reporting of faults or failures)
- Monitoring and Control Testing (all II&C equipment monitors conditions and detects anomalies and properly reports them)
- Stand-by Operations (other than normal mode connected to the local power grid)
- Shut-down operations (bringing all equipment off-line).

The OTEC Pilot Plant Grid Interface Test Plan Draft is located in Appendix 4.1-3 of this document.

4.1.2.4 OTEC Pilot Plant Monitoring and Control Matrix Draft

The OTEC Pilot Plant Monitoring and Control Matrix Draft describe the data collection performed during normal plant operations. The Matrix is organized in sections for each Segment and includes the Elements, Subsystems, Assemblies, and Components within each element:

- Platform Segment
- Power Generation Segment
- Power Delivery Segment
- Integrated Instrumentation and Control Segment

The OTEC Pilot Plant Monitoring and Control Matrix Draft is located in Appendix 4.1-4 of this document.

4.1.2.5 OTEC Pilot Plant Operational Testing Matrix Draft

The OTEC Pilot Plant Operational Testing Matrix Draft describes the OTEC Pilot Plant System Testing to be performed during the Operational Phase (2 years). This Matrix is also organized in sections for each Segment and includes the Elements, Subsystems, Assemblies, and Components within each element:

- Platform Segment
- Power Generation Segment
- Power Delivery Segment
- Integrated Instrumentation and Control Segment

The OTEC Pilot Plant Operational Test Matrix Draft is located in Appendix 4.1-5 of this document.

4.2 Integration and Test Flow

4.2.1 Test Flow Diagram

The flow of testing for the OTEC Pilot Plant is based on the OTEC System Logical Architecture mentioned earlier. An OTEC Pilot Plant Physical Architecture (showing all of the systems pieces and parts) and a Test Flow Diagram were also developed and are contained in the Draft Master Test Plan (Appendix 4.1-1). The Test Flow Diagram will be the basis of a Test Sequence Network, to be developed in the next phase, which will add time phasing and show coordination of all test (IV&V) activities with other engineering development tasks.

A sample test flow is shown below in Figure 4-2 using a Remora Warm Water Subsystem pump as the beginning component.

Warm Water Pump Assembly Factory Acceptance Test (FAT)

The starting point of the test flow begins with the lowest level components (i.e. Warm Water Pump) which undergo a Factory Acceptance Test (FAT) to ensure they item comply with the established specifications (requirements) (i.e. Warm Water Pump Specification document). This may consist of a supplier/vendor test with a set of test data or may be a certificate of conformance. The test team may be involved in development of test documentation, witnessing the test or reviewing the final results.

Warm Water Handling Subsystem Integration & Test (I&T)

When it is established that the component (Warm Water Pump) conforms to its requirements it can be integrated into the next level of the architectural hierarchy (Warm Water Handling Subsystem). The warm water pump is joined with the piping, ducting, manifold and valves, the Evaporator, Instrumentation and Control sensors and cabling and associated corrosion and bio-fouling prevention components as applicable. Testing of this Warm Water Handling subsystem would be performed at a land-based test facility or site (LBTF/LBTS) and would verify that the Warm Water Subsystem conforms to its requirements (i.e. Warm Water Subsystem Specification). The other fluid handling subsystems in the Power Cycle (Remora) Element would be tested in a similar manner.

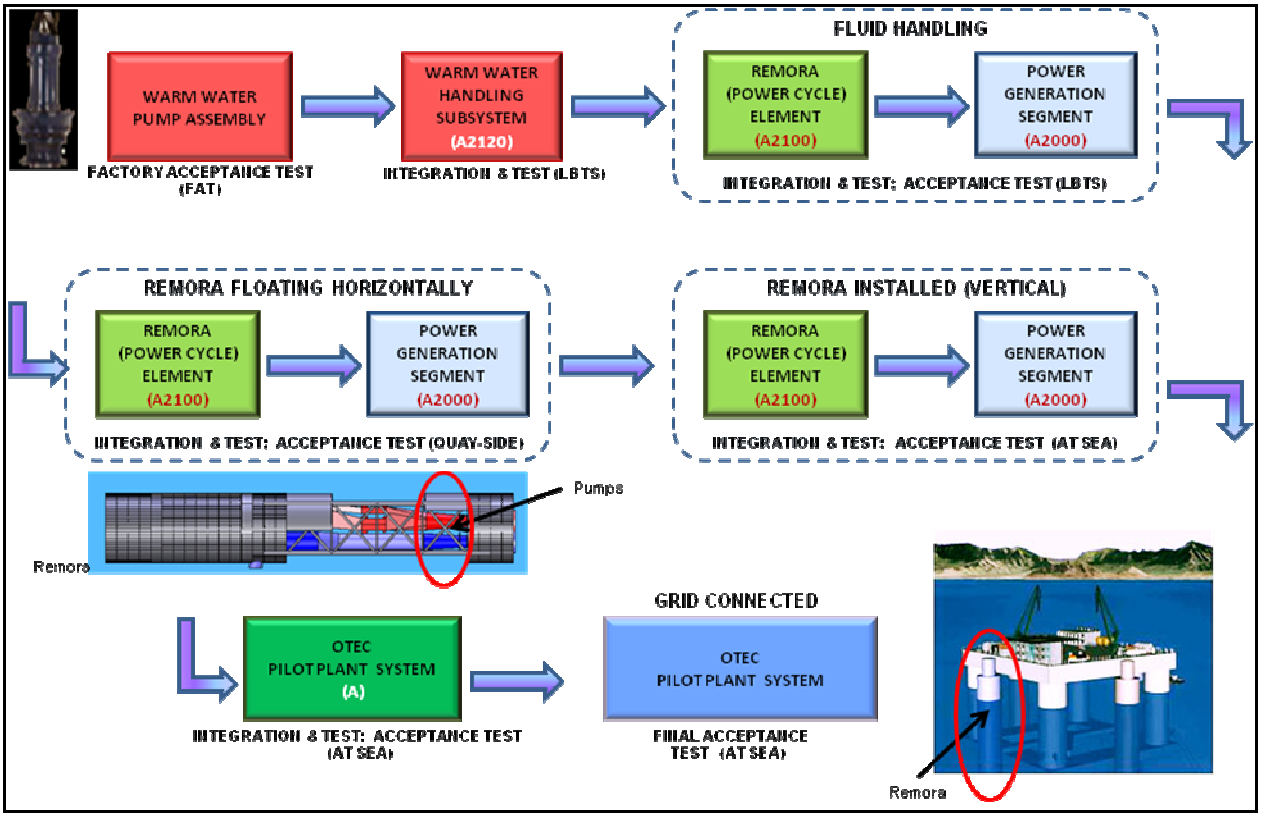


Figure 4-2. Test Flow Example for the Warm Seawater Pump

Fluid Handling Subsystems Integration & Test (I&T)

A Power Cycle (Remora) Element test will be performed using the Warm Water Handling Subsystem, or a representative portion, and the Working Fluid (Ammonia) Handling Subsystem, or portion thereof. The relevant sections of the Power Cycle Element (Remora) Specification are tested/ verified. This testing would take place at a LBTF. Since the subsystems will not be in actual seawater, representative Warm Water will be need to be supplied. The Cold Water Handling Subsystem, or a portion, would be similarly integrated with the Ammonia Handling Subsystem and testing performed. Thereafter, the three Fluid Handling subsystems, without the Hull Structure subsystem, are integrated and tested to verify that the applicable portions of the Remora Element Specification are met. Simulation of components or materials not available may be necessary. This Remora Element Fluid Handling test would most likely be performed at the same LBTF.

A Power Generation Segment test will next be performed involving the Remora Element fluid handling subsystems and Electrical Generation Element subsystems (Turbine-Generator) or representative portions. The applicable sections of the Remora Element Specification, Electrical Generation Segment Specification, and Remora to Electrical Generation Interface Specification are verified. This is an early integration test to gain confidence in the subsystems design. Simulation of components not available or included may be necessary (e.g. the CWP will not have been fabricated at this point). This test would be performed at a LBTF.

Remora Element (Floating Horizontally) Integration & Test (I&T)

The Remora Element fluid handling subsystems will next be installed on the Hull Structure subsystem and again tested at the Element level against the Remora Element Specification. This is a repeat of the earlier Fluid Handling Subsystems test but this time with the Remora Element completely assembled.

This testing may be performed at an LBTF initially, but the main testing will take place with the Remora floating (in the water) in a horizontal orientation to the extent feasible at a dock/quay-side facility. This testing will be limited depending on the capability of the components and subsystems to operate normally in a horizontal attitude and when not mounted to the platform and not directly connected to the platform subsystems (ammonia, electrical, I&C). Methods of supplying fluids and power and control cabling will be devised.

The Power Generation Segment elements/subsystems will next be connected to the floating Remora to the extent feasible and a repeat of the earlier LBTF testing performed. This will involve the Remora Element and Electrical Generation Element subsystems (Turbine-Generator) or representative portions. The applicable portions of the Remora Element Specification, Electrical Generation Segment Specification, and Remora to Electrical Generation Interface Specification are again verified in this new configuration and orientation. This testing will be limited by the availability of seawater and ammonia (e.g. the CWP is not installed).

Remora Element (Installed Vertically on the Platform) Integration & Test (I&T)

This testing will take place “at sea” presumably at the operational site, with the Remora installed on the Platform and all subsystems/elements connected with the possible exception of the Cole Water Pipe (CWP). This testing will be limited until the CWP is completed and installed. A method of supplying cold seawater may need to be devised.

The Power Generation Segment elements/subsystems will next be connected to the floating Remora to the extent feasible and a repeat of the earlier LBTF testing performed. This will involve the Remora Element and Electrical Generation Element subsystems (Turbine-Generator) or representative portions. The applicable portions of the Remora Element Specification, Electrical Generation Segment Specification, and Remora to Electrical Generation Interface Specification are again verified in this new configuration and orientation.

Pilot Plant System Integration & Test (I&T)

This testing will involve each of the four segments of the Pilot Plant System (Platform, Power generation, Power Delivery, and Integrated Instrumentation and Control). The test Sequence Network, to be developed in a later phase, will guide these activities accomplished in a step-wise manner until all segments are operating together. Once this testing is completed the Plant can be operated in a standalone condition (prior to supplying power to a grid system). A Dummy Load Bank will be installed on the platform to allow this to occur. System Validation/Demonstrations will be conducted in turn for each Element or Segment to ensure they meet their respective System Specification and Acceptance Test Requirements. After completion of these activities the Plant will be ready for integration and testing with the local power grid system.

The Pilot Plant to Grid Integration and will be accomplished in two steps; Pilot Plant Standalone Operations and Pilot Plant connected to the Grid. The OTEC Pilot Plant to Grid Interface Test

Plan (Draft) describes the activities for this event. Once these tests are completed, the Pilot Plant will be supplying electrical power to the local Electric Power Grid.

Pilot Plant System Final Acceptance Test (I&T)

The final Validation events will be accomplished once the Pilot Plant is connected to the local power Grid and satisfactorily supplying electrical power and being operated by qualified personnel. Receipt of certifications and approvals to operate the Pilot Plant will be included in these Validation activities.

Following these Final System Acceptance Tests, the Plant will be operated for about two years as the performance, environmental impact, and operation & maintenance costs are measured and evaluated. These activities are described in an OTEC Pilot Plant Operational Phase Test Plan.

4.2.2 List of Planned Testing

The following list summarized the planned testing as currently captured in the Master Test Plan Draft (Appendix 4.1-1). It is organized according to the System Logical Architecture and System Physical Architecture discussed previously.

4.2.2.1 Platform Segment (A1000)

a. Engineering Development & Factory Acceptance Tests (FAT)

Platform Topsides (A1100)

(1) Start-Up Diesel Generator FAT

(2) Auxiliary Diesel Generator FAT

(3) Platform Control Center FAT

(4) Platform Electrical Lighting Subsystem FAT

(5) Platform Electrical Subsystem (Pumps) FAT

Platform Sea keeping (A1300)

(1) Tensioning Subsystem FAT

(2) Tension Members Subsystem FAT

(3) Seafloor Anchors Subsystem FAT

b. Subsystem Integration & Test

Platform Topsides (A1100)

(1) Platform Electrical Plant Subsystem Integration & Test

(2) Platform Communication & Control Subsystem Integration & Test

(3) Platform Auxiliary Subsystem Integration & Test

(4) Platform Outfit & Furnishing Subsystem Integration & Test

(5) Platform Management Element (II&C) Software Integration & Test

Station keeping Element (A1300)

(1) Tensioning Subsystem Integration & Test

(2) Tension Subsystem Integration & Test

(3) Seafloor Subsystem Integration & Test

c. Element Integration & Test

(1) Platform Topsides Element Integration & Test (A1100)

(2) Platform Hull Element Integration & Test (A1200)

(3) Platform Station keeping Element Integration & Test (At Sea) (A1300)

d. Segment Integration & Test

(1) Platform Segment Integration & Test (Quay-Side)

(2) Platform Segment Acceptance Test (At Sea)

4.2.2.2 Power Generation Segment (A2000)

a. Engineering Development & Factory Acceptance Testing

(1) Power Cycle (Remora) (A2100)

(2) Working Fluid (WF) [Ammonia] Pumps & Pods FAT

(3) WF Demister FAT

(4) WF Reservoir FAT

(5) WF Piping & Valves FAT

(6) WF Piping Hydrostatic Pressure (Hydro) Tests

(7) Warm Water (WW) Pumps FAT

(8) WW Intake Ducting & Screens FAT

(9) WW Discharge Ducting FAT

(10) WW Screens FAT

(11) WW Piping & Valves FAT

(12) WW Piping Hydro Tests

(13) WW Screens Environmental Impact Tests

(14) Cold Water (CW) Pumps FAT

(15) CW Intake Ducting & Screens FAT

(16) CW Discharge Ducting FAT

(17) CW Screens FAT

(18) CW Piping & Valves FAT

(19) CW Piping Hydro Tests
(20) CW Screens Environmental Impact Tests
(21) Evaporator Engineering Evaluation Test (LM)
(22) Evaporator Engineering Evaluation Test (NELHA)
(23) Evaporator Environmental Impact Tests
(24) Evaporator Factory Acceptance Test (FAT)
(25) Evaporator Bio-fouling & Corrosion Test)
(26) Evaporator Factory Integration &Test
(27) Condenser Engineering Evaluation Test (LM)
(28) Condenser Engineering Evaluation Test (NELHA)
(29) Condenser Environmental Impact Tests
(30) Condenser Factory Acceptance Test (FAT)
(31) Condenser Bio-fouling & Corrosion Test
(32) Condenser Factory Integration & Test
(33) Cold Water Pipe (CWP) Subsystem Engineering Development Test
(34) Cold Water Pipe (CWP) (A2200)
(35) CWP Termination Engineering Development Test
(36) CWP Connection Engineering Development Test
(37) Electrical Generation (A2300)
(38) Turbine Factory Acceptance Test (FAT)
(39) Generator Factory Acceptance Test (FAT)
(40) Turbine-Generator Factory Acceptance Test (FAT)

b. Subsystem Integration & Test

Power Cycle (Remora) (A2100)

(1) WF Subsystem Electrical (Pumps) Integration & Test
(2) WF Subsystem I & C Integration & Test
(3) WW Subsystem Electrical (Pumps) Integration & Test
(4) WW Subsystem I & C Integration & Test
(5) CW Subsystem Electrical (Pumps) Integration & Test
(6) CW Subsystem I & C Integration & Test
(7) Power Cycle (Remora) Working Fluid Subsystem Integration & Test

(8) Power Cycle (Remora) Cold Water Subsystem Integration &Test

(9) Power Cycle (Remora) Warm Water Subsystem Integration &Test

(10) Power Cycle (Remora) Working Fluid Subsystem Piping Hydro Test

(11) Power Cycle (Remora) Cold Water Subsystem Piping Hydro Test

(12) Power Cycle (Remora) Warm Water Subsystem Piping Hydro Test

(13) Power Cycle (Remora) Working Fluid Subsystem Acceptance Test

(14) Power Cycle (Remora) Cold Water Subsystem Acceptance Test

(15) Power Cycle (Remora) Warm Water Subsystem Acceptance Test

(16) Power Cycle (Remora) Hull Subsystem Integration & Test

(17) Power Cycle (Remora) Hull Subsystem Acceptance Test

Cold Water Pipe (A2200)

(1) CWP Subsystem Anti-Bio-fouling Integration & Test

(2) CWP Subsystem I&C Acceptance Test

(3) CWP Subsystem Qualification/Acceptance Test

(4) CWP Termination Subsystem Qualification/Acceptance Test

(5) CWP Connection Subsystem Qualification/Acceptance Test

Electrical Generation (A2300)

(1) Turbine-Generator I&T

c. Element Integration & Test

(1) Power Cycle (Remora) Fluid Handling Integration & Test (LBTS) (A2100)

(2) Power Cycle (Remora) Element I&C Integration & Test (LBTS) (A2100)

(3) Power Cycle (Remora) Element Integration & Test (Quay-Side) (A2100)

(4) Power Cycle (Remora) Element Acceptance Test (At Sea) (A2100)

(5) CWP Fabrication System INCO Tests (Quay-Side) (A2200)

(6) CWP Fabrication System Acceptance Test (At Sea) (Step3) (A2200)

(7) Electrical Generation Segment Instrumentation & Control (I&C) Integration & Test (A2300)

(8) Electrical Generation Segment I&C Acceptance Test (A2300)

(9) Electrical Generation Segment Integration & Test (Quay-Side) (A2300)

(10) Electrical Generation Segment Acceptance Tests (Quay-Side) (A2300)

d. Segment Integration & Test

(1) Power Generation Segment Integration & Test (LBTS)

(2) Power Generation Segment Integration & Test (Quay-Side)

(3) Power Generation Segment Acceptance Tests (Quay-Side)

4.2.2.3 Power Delivery Segment (A3000)

a. Engineering Development & Factory Acceptance Testing

Platform Substation (A3110)

(1) Platform Substation Switchgear FAT

(2) Platform Substation Transformer FAT

(3) Platform Substation Batteries FAT

(4) Platform Substation Power Cabling FAT

(5) Platform Substation Control Cabling FAT

(6) Platform Substation Supervisory Control and Data Acquisition (SCADA) FAT

Power Transmission (A3120)

(1) Power Transmission Land Cable FAT

(2) Power Transmission Undersea Suspended Cable FAT

(3) Power Transmission Undersea Seafloor Cable FAT

(4) Power Transmission Undersea Bottom-Laid Cable FAT

(5) Power Transmission Shore Landing Cable Vault FAT

On-Shore Substation (A3130)

(1) On-Shore Substation Switchgear FAT

(2) On-Shore Substation Transformer FAT

(3) On-Shore Substation Batteries FAT On-Shore Substation Power Cabling FAT

(4) On-Shore Substation Control Cabling FAT

(5) On-Shore Substation SCADA FAT

b. Subsystem Integration & Test

Platform Substation (A3110)

(1) Platform Substation Software Integration & Test

(2) Platform Substation Software Acceptance Test

(3) Platform Substation Subsystem Integration & Test

(4) Platform Substation Subsystem Acceptance Test

Power Transmission (A3120)

(1) Power Transmission Cable Subsystem Integration & Test

(2) Power Transmission Cable Subsystem Acceptance Test

On-Shore Substation (A3130)

(1) On-Shore Substation Software Integration & Test

(2) On-Shore Substation Software Acceptance Test

(3) On-Shore Substation Subsystem Integration & Test

(4) On-Shore Substation Subsystem Acceptance Test

c. Element Integration & Test

(1) Electrical Delivery Element Integration & Test (Quay-side) (A3100)

(2) Electrical Delivery Element Acceptance Test (Quay-side) (A3100)

d. Segment Integration & Test

(1) Electrical Delivery Segment Integration & Test (At Sea)

(2) Electrical Delivery Segment Acceptance Test (At Sea)

4.2.2.4 Integrated Instrumentation& Control (II&C) (A4000)

a. Engineering Development & Factory Acceptance Testing

(1) TBD

(2) TBD

(3) TBD

b. Subsystem Integration & Test

Platform Management I&C (A4100)

(1) Platform I&C Subsystem Integration & Test

(2) Platform I&C Subsystem Acceptance Test

(3) Safety, Security, Communications Subsystem I&C Integration & Test

(4) Safety, Security, Communications I&C Subsystem Acceptance Test

Power (Cycle) Management I&C (A4200)

(1) Remora Hull I&C Subsystem Integration & Test

(2) Ammonia I&C Subsystem Integration & Test

(3) Warm Water I&C Subsystem Integration & Test

(4) Cold Water I&C Subsystem Integration & Test

(5) Power Cycle (Remora) I&C Subsystem Integration & Test

(6) Power Cycle (Remora) I&C Subsystem Acceptance Test

(7) CWP I&C Subsystem Integration & Test

(8) CWP I&C Subsystem Acceptance Test

(9) Electrical Generation I&C Subsystem Integration & Test

(10) Electrical Generation I&C Subsystem Acceptance Test

(11) Electrical Delivery Element I&C Integration & Test

(12) Electrical Delivery Element I&C Acceptance Test

Environmental Monitoring Management I&C (A4300)

(1) Environmental Delivery Subsystem I&C Integration & Test

(2) Environmental Delivery Subsystem I&C Acceptance Test

c. Element Integration & Test

(1) Platform Substation Subsystem I&C Integration & Test

(2) Platform Substation Subsystem I&C Acceptance Test

(3) Transmission Cable Subsystem I&C Integration & Test

(4) Transmission Cable Subsystem I&C Acceptance Test

(5) On-Shore Substation Subsystem I&C Integration & Test

(6) On-Shore Substation Subsystem I&C Acceptance Test

(7) II&C Platform Management Element Software Integration & Test (A4100)

(8) II&C Platform Management Element Software Acceptance Test (A4100)

(9) II&C Platform Management Element Integration & Test (A4100)

(10) II&C Platform Management Element Acceptance Test (A4100)

(11) II&C Power (Cycle) Management Element Software Integration & Test (A4200)

(12) II&C Power (Cycle) Management Element Software Acceptance Test (A4200)

(13) II&C Power (Cycle) Management Element Integration & Test (A4200)

(14) II&C Power (Cycle) Management Element Acceptance Test (A4200)

(15) II&C Environmental Monitoring Management Element Software Integration & Test (A4300)

(16) II&C Environmental Monitoring Management Element Software Acceptance Test (A4300)

(17) II&C Environmental Monitoring Management Element Integration & Test (A4300)

(18) II&C Environmental Monitoring Management Element Acceptance Test (A4300)

d. Segment Integration & Test

(1) II&C Segment Integration & Test (At Sea)

(2) II&C Segment Acceptance Test (At Sea)

(3) II&C Segment Software Integration & Test (LBTS)

(4) II&C Segment Software Acceptance Test (LBTS)

(5) II&C Segment Integration & Test (LBTS)

(6) II&C Segment Acceptance Test (LBTS)

(7) II&C Segment Integration & Test (Quay-side)

(8) II&C Segment Acceptance (Quay-side)

4.2.2.5 Pilot Plant System

a. System Integration & Test

(1) System Environmental Qualification Tests

(2) Electromagnetic Interference (EMI) Test

(3) System Integration & Test (Shipyard)

(4) System Integration & Test (Quay-Side)

(5) System Integration & Test (At Sea)

(6) System Acceptance Test (At Sea)

(7) Pilot Plant System to Grid Interface Integration & Test (At Sea)

(8) Pilot Plant System to Grid Interface Acceptance Test (At Sea)

(9) Pilot Plant System Final Acceptance Test (At Sea)

b. System Operational Tests

(1) Supportability Demonstrations

(2) Performance Tests

(3) Environmental Impact Tests

(4) Other - TBD

4.2.2.6 Cold Water Pipe (CWP) Fabrication System

a. Engineering Development & Factory Acceptance Testing

(1) CWP Gripper/Handler Engineering Development Tests

(2) CWP Critical Restart Engineering Development Tests

(3) CWP Fabrication Apparatus Engineering Development Test (Step 0) (LBTS)

(4) CWP Fabrication Apparatus Engineering Integration Test (Step 1) (LBTS)

(5) CWP Fabrication Environmental Enclosure HVAC Engineering Test

(6) CWP Fabrication Environmental Enclosure Fabric Handling Engineering Test

(7) CWP Fabrication Environmental Enclosure Compressed Air & Vacuum Handling Engineering Test

(8) CWP Fabrication Environmental Enclosure Core Plank Handling Engineering Test

(9) CWP Core Assembly Region FAT

(10) CWP Fabric Placement/Dispensing Region FAT

(11) CWP Molding Region FAT

(12) CWP Tower Structure/FAT

b. Subsystem Integration & Test

(1) TBD

c. Element Integration & Test

(1) TBD

d. Segment Integration & Test

(1) CWP Gripper/Handler Segment Integration & Test (LBTS?)

(2) CWP Gripper/Handler Segment Acceptance Test (TBD)

(3) CWP Fabrication Apparatus Segment Integration & Test (Step 2) (Quay-side)

(4) CWP Fabrication Apparatus Segment Acceptance Test (TBD)

(5) CWP Fabrication System Integration & Test (Step 3) (At Sea)

(6) CWP Fabrication Environmental Enclosure Segment Integration & Test (Quay-side)

(7) CWP Fabrication Environmental Enclosure Segment Acceptance Test (At Sea)

(8) CWP Fabrication System Installation Segment Integration & Test (Quay-side)

(9) CWP Fabrication System Installation Segment Integration & Test (At Sea)

4.3 Integration and Test Next Steps

In the next phase of engineering development the preliminary work that has been accomplished will need to be updated, refined, and matured to finalize the design and set the stage for development and fabrication activities. The key next steps for the SI&T/IV&V Team to prepare for integration & test events are shown in Table 4-1 as follows:

Table 4-1. OTEC Pilot Plant SI&T Forward Plans/ Next Steps

Plan/Activity	When to Implement	Remarks
Establish Test (IV&V) Team	Pre-FEED	
Review, analyze, and finalize all requirements, specification, and CONOPS	Pre-FEED	
Review DOORS Database requirements, Verification Methods, and Tracing	Pre-FEED	
Refine Draft Pilot Plant Monitoring, Measurement, and Testing Matrix	Pre-FEED	
Refine Draft Pilot Plant Operational Phase Testing Matrix	Pre-FEED	
Define Test Environments	Pre-FEED	
Finalize MTP	FEED	
Define Test facilities, tools and equipment	FEED	
Finalize Draft Pilot Plant Monitoring, Measurement, and Testing Matrix	FEED	
Finalize Draft Pilot Plant Operational Phase Testing Matrix	FEED	
Develop Test Plans and Cases for each test event by calendar priority	Detailed Design	
Finalize System Integration Test Plan	Detailed Design	
Finalize Grid Interface Test Plan	Detailed Design	

5. COST DISCUSSION

5.1 Methodology

The system architecture, as defined by the project team and shown below in Figure 5-1, was used in lieu of a shipboard work breakdown structure (SWBS) to organize costs. Each system, and many of their subordinates (defined in the system architecture as segments, elements, and subsystems), were assigned an owner from among the project team. Owners were not only responsible for system and technology development, but cost estimating as well.

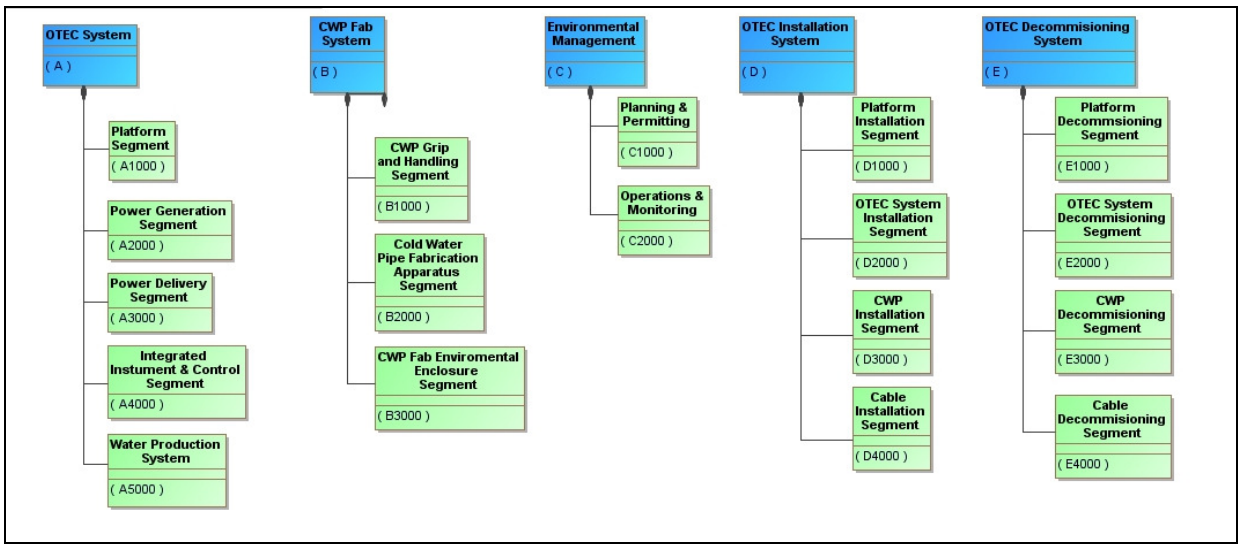


Figure 5-1. System Architecture

In preparing cost estimates, system owners were instructed to apply the following philosophies:

- Granularity aids eventual accuracy. Dividing system, segment, element, or subsystem costs into multiple line items helps avoid double-counting or omission of cost elements. It also provides more opportunity for offsetting errors.
- Where possible, the separation of labor and material costs will allow the final estimate to be more easily updated in the future. Labor and material costs will escalate at different levels in years to come, with material costs being generally more volatile than labor. Estimators were encouraged to generate "composite" labor rates representative of broad groups of crafts or expertise.
- A basis of estimate associated with each line item of the cost estimate will provide future users and reviewers a better opportunity to recreate or update the estimate.

System owners were provided with standardized spreadsheets, which included the following fields for each line item:

A. Element. A verbal description of the item being estimated.

B. Alias. Any alternative description used by the estimator for the same line item. For instance, if the line item is from a SWBS-based estimate, this might be the SWBS number and descriptor.

C. Qty. The quantity (or number) of units being used in the basis of estimate. For example, if there are two hydraulic cranes to be installed, this would be "2." If the item is shell plate for the pontoon deck, it would be kgs or tonnes.

D. Units. These are the units of measure being used to quantify the line item; e.g., "each" or "tonnes" or "square meters."

E. Man-hours per unit. Where the individual line item can be segmented into materials and labor, it should be. Man-hours per unit is the number of labor hours expected to manufacture, install, and integrate the item into the finished assembly. If it is subject to its own shop testing prior to integration, that effort should be included here.

F. Man-hours. This calculated number is the number of units times the unit labor cost.

G. Mhr Rate. The man-hour rate is the US$ representative of an appropriate overall rate for the system being installed.

H. Labor. This calculated number is the cross product sum of labor rate and man-hours.

I. Material Rate. This is the per-unit bare cost of the materials used in manufacturing the line item, at the level it will most likely be procured for integration into the system. For instance, the cranes are likely to be acquired as a unit, complete with subbase, but excluding foundations. The material rate for this would be the acquisition cost of the cranes ex-factory. For raw materials like steel plate, this would be the unit cost of the steel ex-foundry.

J. Material. This calculated number is the number of units times the unit material rate.

K. S/C. Any surcharges associated with delivering the materials to, or acceptance inspections at the integration site, are collected here. Examples are inbound freight charges, drayage fees, special receiving inspections or tests, and import duties.

L. Material Markup. This is the material handling fee with a profit margin for the integrator. In the absence of better information, the estimator may assume a value of 15%.

M. Allowances. The estimator may use this category of expense if he or she believes that the prices on which the estimate is based are suspect. The estimator is encouraged to include an allowance for technological maturity or expected future cost fluctuations, and a basis therefor.

N. Contractor Contingency. This column should be left blank. Contingency budgets will be the subject of review after the estimate has been assembled.

O. Escalation. This column has been reserved for re-estimating the project in the future, when acquisition schedules firm.

P. Capex Category. Select cost category from drop-down menu, to be used for data mining at a later date, as follows:

- Controls
- Power Block Installation
- Turbines & Generators
- Seawater Pipes & Pumps
- Power Export Cable
- Heat Exchangers
- Vessel
- Unallocated

T. Recurring Cost (Y/N). Recurring costs include anything that would have to be spent to build a second unit of this class. Steel is recurring cost. Engineering design is not.

5.2 Cost Basis

Estimators applied the following global basis of estimate to their work:

- Time Value of Money shall be 2010 Dollars.
- Estimates shall represent Bare Costs to Prime Contractor.
- Estimates shall not include any contingencies, except those specifically identified as "allowances" for technological unknowns.
- Estimates for any components or assemblies not integrated with the platform at the builder's yard (such as turbines and mooring systems) shall reflect its acquisition cost as delivered and installed in Hawaii.
- Engineering Costs shall be included by Segment, Element, or System, as appropriate, and flagged as either recurring or non-recurring.

5.3 Results

In keeping with the system architecture shown above, current cost estimates for capital acquisition and installation are shown in Table 5-1. Note that segment summaries have been provided for the OTEC system expense.

Table 5-1. Capital Expense

System	Segment Subtotals $	SYSTEM TOTALS $	NOTES / BASIS / KEY DRIVERS
Program Level Expenses		$6,900,000	
OTEC System Expenses		$324,700,000	US Construction base case
Platform Segment	$193,500,000		Engineering & Management - $35mm, Outfitting - $30mm, Steel - $52mm
Power Generation Segment	$110,500,000		Remora hull - $22mm, HX - $40mm
Power Delivery Segment	$19,600,000		Subsea cable - $14mm
Integr. Instr . & Cntl Segment	$1,100,000		
OTEC Installation System		$45,900,000	Includes 4-leg mooring - $15mm, export cable installation - $25mm
CWP Fabrication System		$14,300,000	
Environmental Management System		$5,600,000	
OTEC Decommissioning System		$3,000,000	Accrual for Future Activity Cost
Total OTEC Capex		**$400,400,000**	

The base case assumes new construction in the US, 5MW of net generating capacity, no desalination capability, with station keeping provided by a temporary 4-leg mooring system. The complete cost model and estimate is competition sensitive. It has been delivered to the NAVFAC as a separate, proprietary addendum to this report, with limited distribution.

Two key alternatives to this base case system were investigated: more robust mooring designs, and foreign construction of the platform. As presently designed, the export power cable is at risk if the 4-point mooring system suffers a failure in one of its legs. While the platform can be held more or less on station by the remaining three legs, it will assume a different equilibrium position and exhibit a different watch circle. The new position and potential excursions around that point could overstress the electrical cable and cause it to part. Two alternative 8-point moorings were investigated that can better withstand the single-line failure case without causing damage to the export cable. One was designed to meet the standards for a permanent offshore installation (nominally 25 years duration), while the other met the requirements for a temporary installation (nominally 2 years duration). The former added about $18 million to the capital expenditure, while the latter added approximately $6 million. These alternative configurations should be considered as part of the overall risk management as the project moves forward.

As can be seen in Table 5-1, above, the platform itself represents almost half of the total capital expense. Its base case assumed construction in a US yard. It was estimated that construction in the Far East could reduce the capital cost by about $42 million.

6. COMMERCIALIZATION PLAN OVERVIEW

The OTEC Commercialization Plan describes the work to be performed for transitioning the OTEC technology from its present R&D status to a fully commercial product where performance, cost and schedule to produce OTEC systems can be given to a customer with sufficiently high confidence that a fixed price contract can be established for the purchase.

The document describes the approach to OTEC commercialization as it has developed during the NAVFAC OTEC Study Contract. The document has been reviewed by the major stakeholder in the OTEC Project including the LM Team, LM Management, NAVFAC Management, NOAA representatives, Dept. of Energy representatives, and other interested parties. The time frame for the Commercialization Plan spans the thirteen year period from 2007 through 2019. The plan is based upon continued R&D work to reduce technical risk, construction of a Pilot Plant as a risk reduction step to verify cost and schedule predictions, and the approach for constriction and assembly for the first 100 MW Commercial Plant. The first Commercial Plant is planned for Oahu and the second Commercial Plant is planned for Guam. The next few Commercial OTEC Plants will likely be sited off Oahu.

The Commercialization Plan is a stand-alone addendum to this document for use by the LM Team as a co-ordination tool and provides a mechanism for communicating the general plans of the OTEC program to interested organizations. In conjunction with the OTEC Business Plan, the Commercialization Plan offers the Finance community with a clear picture of the financial opportunities available from commercial OTEC systems.

The table below lists each of the major sections of the Commercialization Plan and provides a brief summary statement for each section.

Table 6-1. Overview of Commercialization Plan

Section	Summary
1. Executive Summary for NAVFAC OTEC Study Commercialization Plan	Overview of the document with Purpose, Scope, Approach, etc.
2. Background	Describes the OTEC power cycle concept and presents the thermal temperature difference resource available to OTEC systems.
3. OTEC Modern History and Current Status	Technology status by mid-2009
4. OTEC Commercialization Roadmap	Overall program WBS, program phases, engineering, business establishment, and major program milestones.
5. Environmental Compliance & Permits	Description of federal, state, and local permitting required for the Pilot Plant and the first Commercial Plant on Oahu, HI

Section	Summary
6. Pilot Plant Construction & Installation	Description of Pilot Plant construction and installation approach. Describes facilities and sequence of events. Includes laying marine power cable and interface on Pearl Harbor (or other) base. Also validation and demonstration work with follow-on options.
7. 100 MW Commercial Plant Construction & Installation	Same as Pilot Plant above. Refine timeline estimates and define HECO power assessment tasks leading to I/F to grid.
8. Commercial OTEC Operations under LLC	Describes operations, personnel, support equipment, training, safety planning, identifies any certification that may be needed. Same for maintenance. Refines cost estimates for both activities.
9. OTEC Integration into the Oahu Grid	Describes HECO's plans for integrating OTEC onto the grid over the next 30 years along with plant retirement. Consistent with IRP-3 and 4.
10. Plan of Action and Milestones with Funding Profile	Greater definition of program phases and shows required funding by year.
11. Responsibilities Timeline	Description of the responsibilities of the major stakeholders during the different phases.
12. OTEC Commercialization Risks and Benefits	Identification and ranking of risks in the Pilot Plant phase and the 100 MW Commercial phase; identify mitigation approaches.
13. Vision of the Future	Describes long-range vision leading to large grazing OTEC plants in the open ocean. Separate R&D effort to miniaturize OTEC for remote DoD bases is identified.
14. Conclusions	Conclusions that can be drawn from the Commercialization Plan
15. Recommendations	Recommendations to the stakeholders resulting from the Commercialization Plan

7. CONCLUSIONS

Lockheed Martin supported by Makai Ocean Engineering, John Halkyard & Associates, Sound & Sea Technology, The Glosten Associates, G. Noland & Associates, Planning Solutions Inc, Navatek, OCEES, and E3Tek, completed a system design study for an OTEC Pilot Plant. This effort is a key milestone leading to eventual OTEC commercialization, and ultimately the ability to purchase OTEC generated electricity from privately developed OTEC facilities. This work was performed for the Naval Facilities Command Engineering Support Center, Port Hueneme under contract N62583-09-C-0083 initiated on 21 August 2009. This report provides the results of the System Design task.

It should be clear from this report that designing an OTEC system requires the skill of multiple disciplines. Every member of the Lockheed Team brings offshore, energy, and engineering expertise to further OTEC commercialization. The Lockheed Martin team worked in an Integrated Product Team environment where members had individual responsibilities and contributed in many cases to multiple teams. Lockheed was responsible for overall systems engineering, electrical delivery, instrumentation & control, CWP termination, environmental management, and contract conduct. Makai Ocean Engineering was responsible for power generation and the CWP/platform interface during CWP fabrication. John Halkyard & Associates (The Glosten Associates, Houston Offshore Engineering, Horton Wison Deepwater) was responsible for platform design and associated metocean assessments. G. Noland & Associates contributed the Commercialization Plan. Planning Solutions Inc provided the environmental inputs needed to understand requirements for permits. Navatek contributed CFD and power cycle packaging to Makai. OCEES developed the water production report. E3Tek contributed heat exchanger expertise and overall systems perspectives. The Glosten Associates also provided the structure and the roll up of the cost estimates. This study is the result of significant efforts on all parties.

A pilot plant design concept was developed to address key top level requirements including demonstration of a design that could be scaled to utility generation capacities with minimal additional development activity. The concept incorporated a semi-submersible platform meeting stability requirements for long term deployment in Hawaii, a modular power generation design using low-risk components, and deployment to transmit the generated electricity to Pearl Harbor navy base via an undersea cable. The key OTEC challenge is economic. The ability to develop a credible cost estimate requires significant design work to ensure the many technical details are understood to the level seen in this report.

The more significant conclusions of this study are:

- OTEC is technically practical and economically practical at larger capacities.
- A development program can put a pilot plant on line by 2014 given adequate funding is authorized and appropriated.
- Environmental concerns are believed to be minimal and can be addressed by proper design and operation.

- Successful pilot plant operation is expected to lead directly to private financing for commercial scale power plants.
- The next step is to assess this report against availability of funding resources. The top level requirements driving the design shown in this report can be relaxed to reduce the cost of a pilot plant, but only at the expense of those requirement reductions. Interactions between the Navy and the design team are needed to provide the Navy with impacts and assessments for decision making.

8. ACRONYMS

Acronym	Definition
3d	Three-dimensional
ABS	American Bureau of Shipping
AC	Alternating Current
AFB	Air Force Base
AFFF	Aqueous Film Forming Foam
AHV	Anchor Handling Vessel
AIS	Air Insulated Switchgear
AIS	Air Insulated Switchgear
AL	Aluminum
ANSI	American National Standards Institute
API	American Petroleum Institute
ASME	American Society Of Mechanical Engineers
ASTM	American Standard of Testing Materials
ATE	Automated Test Equipment
ATP	adenosine 5'-triphosphate
BA	Biological Assessment
BCS	Ballast Control System
BHP	Brake Horsepower
BS	Breaking Strength
BULL	Bulletin
C&CC	Command and Control Center
C&CS	Command and Control System
CA	California
CAA	Clean Air Act
CB	Center of Buoyancy
CD	Consistency Determination
CDRL	Contract Data Requirements List
CEROS	Center of Excellence in Ocean Systems
CFD	Computational Fluid Dynamics
CFR	Code of Federal Regulations
CG	Center of Gravity
CIA	Cultural Impact Analysis
CNO	Chief of Naval Operations
COE	Corps of Engineers
CONOPS	Concept of operations
COTS	Commercial Off The Shelf
CPT	Cone Penetration Testing
CTD	Conductivity, Temperature, Depth
CW	Cold Water

CWA	Clean Water Act
CWB	Clean Water Branch
CWP	Cold Water Pipe
CZM	Coastal Zone Management
CZMA	Coastal Zone Management Act
DAR	Division of Aquatic Resources
DC	Direct Current
DOE	Department of Energy
DOORS	Dynamic Object Oriented Requirements System
DP	Dynamic Positioning
DVT	Design Verification Test
EA	Environmental Assessment
EEIPS	Extra Extra Improved Plow Steel
EFDC	Environmental Fluid Dynamics Code
EIPS	Extra Improved Plow Steel
EIS	Environmental Impact Statement
EMC	Electro-magnetic Conductance
EMF	Electromagnetic Frequency
EMI	Electro-magnetic Interference
EMP	Electro-Magnetic Pulse
EMS	Environmental Management System
EPA	Environmental Protection Agency
EQT	Environmental Qualification Tests
ESA	Endangered Species Act
ESD	Electro Static Discharge
FAT	Factory Acceptance Tests
FCS	Facility Control System
FE	Finite Element
FEA	Finite Element Analysis
FEED	Front End Engineering Design
FGS	Fire and Gas Detection System
FMECA	Failure Modes Effects And Criticality Analysis
FONSI	Finding of No Significant Impact
FPI	Floating Production Installations
FQT	Formal Qualification Test
FRP	Fiberglass Reinforced Plastic
FSW	Friction Stir Welding
FWS	Fresh Water System
FY	Fiscal Year
GA	General Arrangement
GALV	Galvanized
GE	General Electric
GFI	Government Furnished Information

GIS	Gas Insulated Switchgear
GPS	Global Positioning System
HARP	HARmonic Phase loads analysis software
HDD	Horizontal Directional Drilling
HECO	Hawaiian Electric Company
HI	Hawaii
HMI	Human Machine Interface
HOE	Houston Offshore Engineering
HOS	Hornbeck Offshore Services
HOTS	Hawaii Ocean Timeseries
HP	Horse Power
HPLC	High Performance Liquid Chromatography
Hs	Significant Wave Height
HVAC	Heating Ventilation and Air Conditioning
HWD	Horton Wison Deepwater
HX	Heat Exchanger
I&C	Instrumentation and Control
ICEA	Insulated Cable Engineers Association
ICSS	Integrated Control and Safety System
ID	Identifier
ID	Inner Diameter
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical & Electronics Engineers
II&C	Integrated Instrumentation and Control
IMMS	Integrated Marine Monitoring System
IMMS	Integrated Marine Monitoring System
IMO	International Maritime Organization
INCO	Integration and Checkout/Test
INCOSE	International Council of Systems Engineering
INU	Inertial Navigation Unit
IPT	Integrated Product Team
IR&D	Independent Research and Development
IRP	Integrated Resource Planning
ISO	International Standard Organization
ISO	International Standards Organization
IWRC	Independent Wire Rope Core
Ixx	Mass moment of inertia about the x axis
Iyy	Mass moment of inertia about the y axis
Izz	Mass moment of inertia about the z axis
JBPHH	Joint Base Pearl Harbor – Hickam
ksi	kilo-pound per square inch
kV	kilo Volts
kVAR	kilovolt-ampere reactive

KW	Kilowatt
kxx	Gyradius about the x axis
kyy	Gyradius about the y axis
kyy	Gyradius about the z axis
LAMP	Large Amplitude Motions Program
LBTF	Land Based Test Facility
LBTS	Land Based Test Site
LCD	Longitudinal Center of Buoyancy
LCG	Longitudinal Center of Gravity
LCP	Local Control Panels
LDS	Loads
LDSX	Load x axis
LDSY	Load y axis
LDSZ	Load z axis
LLC	Limited Liability Company
LM	Lockheed Martin
LO	Lower
LS	Landing Site
MARPOL	International Convention for the Prevention of Pollution From Ships
MASA	Mobilization and Staging Area
MATLAB	Matrix Laboratory
MBL	Mean Breaking Load
MCBH	Marine Corps Base Hawaii
MCC	Master Control Center
MCDA	Multi-Criteria Decision Analysis
MCF	Multi-Column Floater
MCP	Master Control Panel
MD	Maryland
MGD	Million Gallons per Day
MIL	Military
MK	Mark
MMPA	Marine Mammal Protection Act
MMS	Minerals Management Service
MODU	Mobile Offshore Drilling Unit
MOTEM	Makai OTEC Thermodynamic and Economic Model
MS2	Mission Systems & Sensors
mt	Metric tonne
MTP	Master Test Plan
MV	Medium Voltage
MVA	Mega Volt Ampere
MW	Megawatt
MWe	Megawatts, electric
NAVFAC	Naval Facilities Engineering Command

NE	North East
NELHA	Natural Energy Lab of Hawaii Authority
NEMA	National Electrical Manufacturer's Association
NEPA	National Environmental Policy Act
NFESC	Naval Facilities Engineering Service Center
NFPA	National Fire Protection Association
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollution Discharge and Elimination
NPSH	Net Positive Suction Head
NSFDG	Naval Support Facility Diego Garcia
NW	North West
OCCL	Office of Coastal & Conservation Lands
OCEES	Ocean Engineering and Energy Systems
OD	Outer Diameter
ONR	Office of Naval Research
OPNAVINST	Office of the Chief of Naval Operations Instruction
OSHA	Occupational Safety and Health Act
OTEC	Ocean Thermal Energy Conversion
OTECA	OTEC Act of 1980
P&ID	Piping and Instrumentation Diagram
PANAX	Panama Canal
PCS	Process Control System
PDMS	Piping Design Management System
PEAMMP	Proponent's Environmental Assessment, Management and Monitoring Plan
PF	Power Factor
PFM	Policy File Memorandum
PID	Proportional Integral Derivative
PLC	Programmable Logic Controller
PMRF	Pacific Missile Range Facility
POL	Petroleum, Oil and Lubricants
PSD	Process Shutdown
PSI	Pacific Shipyard, Inc. in Oahu, Hawaii
PSV	Pressure Safety Valves
PVC	Polyvinyl Chloride
RAO	Response Amplitude Operators
RCRA	Resource Conservation and Recovery Act
RFP	Request For Proposal
ROD	Record of Decision
ROV	Remotely Operated Vehicle
RP	Recommended Practice
RPM	Revolutions Per Minute
SBIR	Small Business Innovation Research

SCADA	Supervisory Control and Data Acquisition
SE	System Engineering
SECNAVINST	Secretary of the Navy Instruction
SEI&T	System Engineering, Integration and Test
SEIPT	System Engineering Integrated Product Team
SI	International System of Units
SI	System Integration
SIP	System Integration Plan
SME	Subject Matter Expert
SOT	System Operational/Operability Test
STEP-R	Strategic Environmental Planning Roadmap
SVR	Steel Vessels
SW	Sea Water
SWBS	Ship Work Breakdown Schedule
SWRO	Sea Water Reverse Osmosis
TBD	To Be Determined
TBR	To Be Reviewed
TCG	Transverse Center of Gravity
TEAAC	Totally Enclosed Air to Air Cooled
TLC	Total Lifecycle Cost
TLI	Tank Level Indicators
TLR	Top Level Requirements
TN	Technical Note
Tp	Peak Wave Period
UN	United Nations
UP	Upper
UPS	Uninterruptable Power Supply
US	United States
USACE	US Army Corps of Engineers
USCG	United States Coast Guard
USFWS	United States Fish & Wildlife Service
USGS	United States Geological Survey
UV	Ultra Violet
V L-L	Voltage Line-to-Line
VA	Virginia
VAC	Volts Alternating Current
VCG	Vertical Center of Gravity
VDC	Volts Direct Current
WAMIT	Wave Analysis Massachusetts Institute of Technology,
WBS	Work Breakdown Structure
WF	Working Fluid
WL	Water Line
WSD	Working Stress Design

WW	Warm Water
XLPE	Cross-linked Polyethylene

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NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-1
Platform General Arrangement Drawings
OTEC-2010-001

17 September 2010

Prepared for:

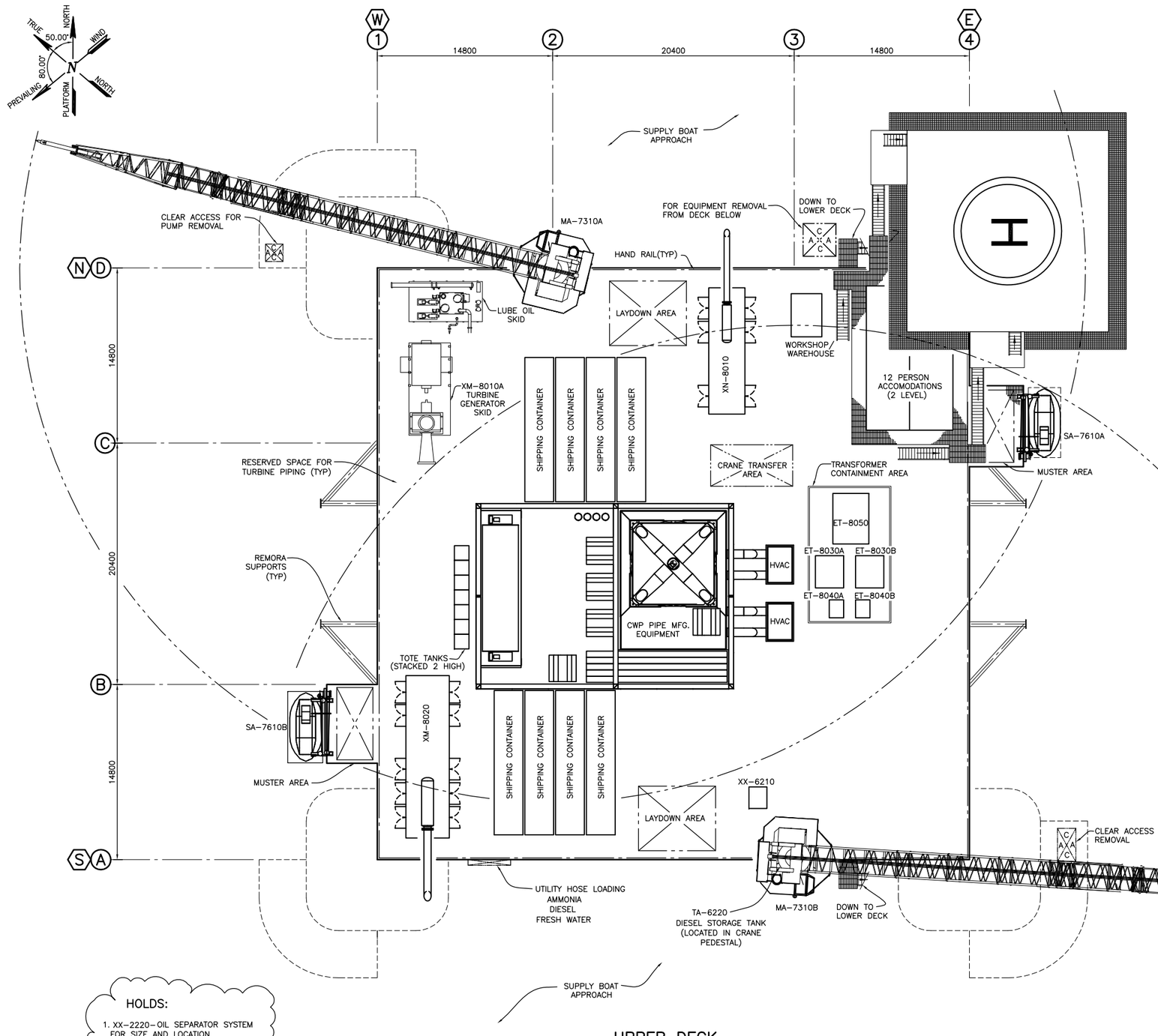
Naval Facilities Engineering Command
Naval Facilities Engineering Service Center (NFESC)
1100 23rd Avenue
Port Hueneme, CA 93043-4370
Attn: Mr. Brian Cable, Contracting Officer Representative

Prepared by:

Lockheed Martin MS2
9500 Godwin Drive
Manassas, VA 20110

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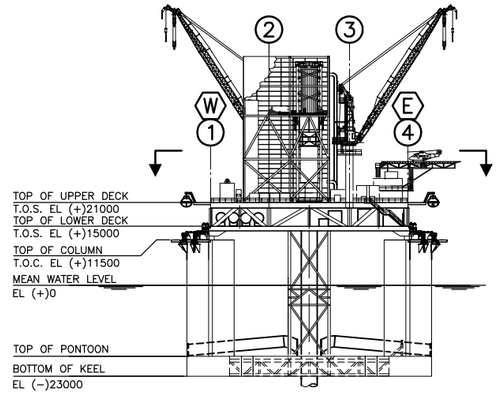
TAG NO.	EQUIPMENT NAME
ET–8030A/B	13.8/4.16kV TRANSFORMER
ET–8040A/B	13.8/4.16kV TRANSFORMER
ET–8050	13.8/33kV SET UP TRANSFORMER
MA–7310A	PEDESTAL CRANE
MA–7310B	PEDESTAL CRANE
SA–7610A	SURVIVAL CRAFT
SA–7610B	SURVIVAL CRAFT
TA–6220	DIESEL STORAGE TANK
XM–8010A	TURBINE GENERATOR
XM–8020	AUXILLARY DIESEL GENERATOR PACKAGE
XN–8010	EMERGENCY GENERATOR PACKAGE
XX–2220	OIL SEPARATOR SYSTEM
XX–6210	DIESEL TRANSFER SKID



UPPER DECK
T.O.S. EL.(+)21000

HOLDS:

1. XX–2220–OIL SEPARATOR SYSTEM FOR SIZE AND LOCATION



KEY PLAN

REV	DESCRIPTION	BY	DATE
D	UPDATE	CEB	06/16/10
C	UPDATED	CEB	03/18/10
B	UPDATED	CEB	02/04/10
A	ISSUED FOR INFORMATION ONLY	CEB	01/26/10

RELEASE FOR:	DEPT ENGR	PROJ ENGR	DESIGN ENGR	DESIGN LEAD	DATE
PRELIMINARY					
BIDDING					
MATL ORDER					
FABRICATION					

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OTEC CONCEPT 10 MEGAWATT PLATFORM

GENERAL ARRANGEMENT UPPER DECK PLAN (CWP FABRICATION/NO REMORAS)

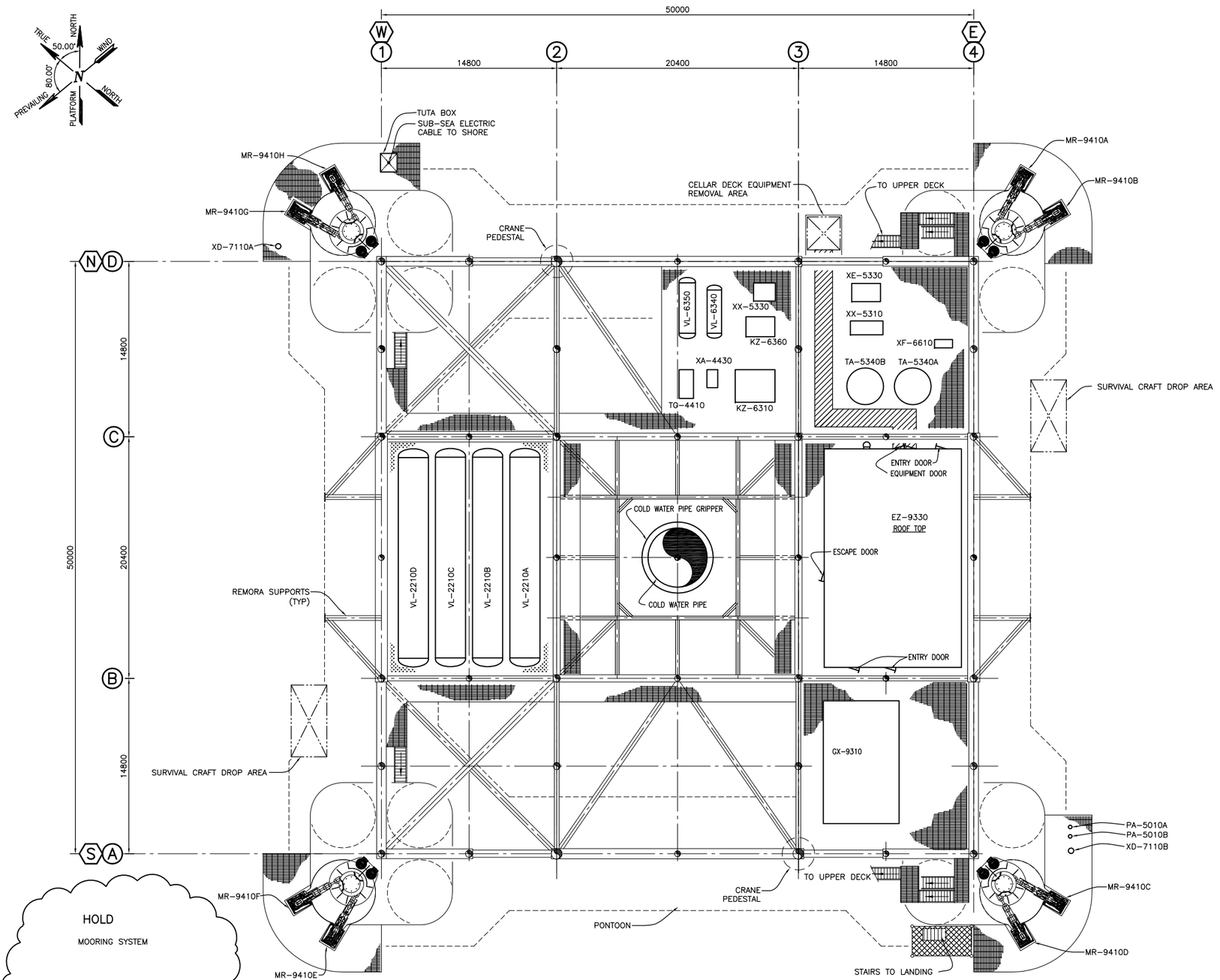
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DWG NO.	SHT	REV
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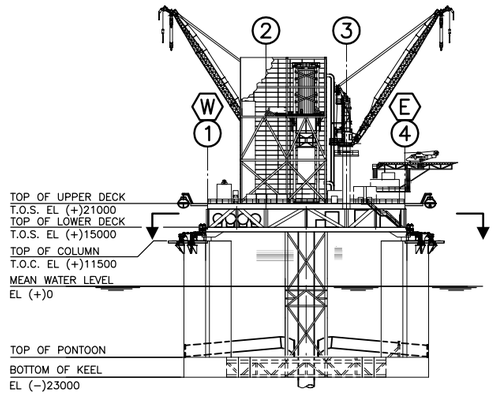
PRELIMINARY

A1 – 594 x 841

TAG NO.	EQUIPMENT NAME
EZ-9330	MCC/SWGR/CTRL BUILDING
GX-9310	MCC ROOM AC PACKAGE
KZ-6310	AIR COMPRESSOR SKID
KZ-6360	BLACK START AIR COMPRESSOR SKID
MR-9410A/B/C/D/E/F/G/H	MOORING EQUIPMENT
PA-5010A/B	SEAWATER LIFT PUMP
TA-5340A/B	FRESH WATER STORAGE TANK
TG-4410	TOPSIDES OILY WATER SUMP TANK
VL-2210A/B/C/D	AMMONIA STORAGE TANK
VL-6340	INSTRUMENT AIR RECIEVER
VL-6350	UTILITY AIR RECIEVER
XA-4430	OILY WATER SEPARATOR
XD-7110A/B	FIREWATER PUMP
XE-5330	POTABLE WATER PRESSURE SET
XF-6610	SEWAGE TREATMENT PLANT
XX-5310	FRESH WATER MAKER
XX-5330	WASHDOWN WATER SKID



LOWER DECK
T.O.S. EL.(+)15000



KEY PLAN

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BIDDING					
MATL ORDER					
FABRICATION					

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OTEC CONCEPT
10 MEGAWATT PLATFORM

GENERAL ARRANGEMENT
LOWER DECK
PLAN
(CWP FABRICATION/NO REMORAS)

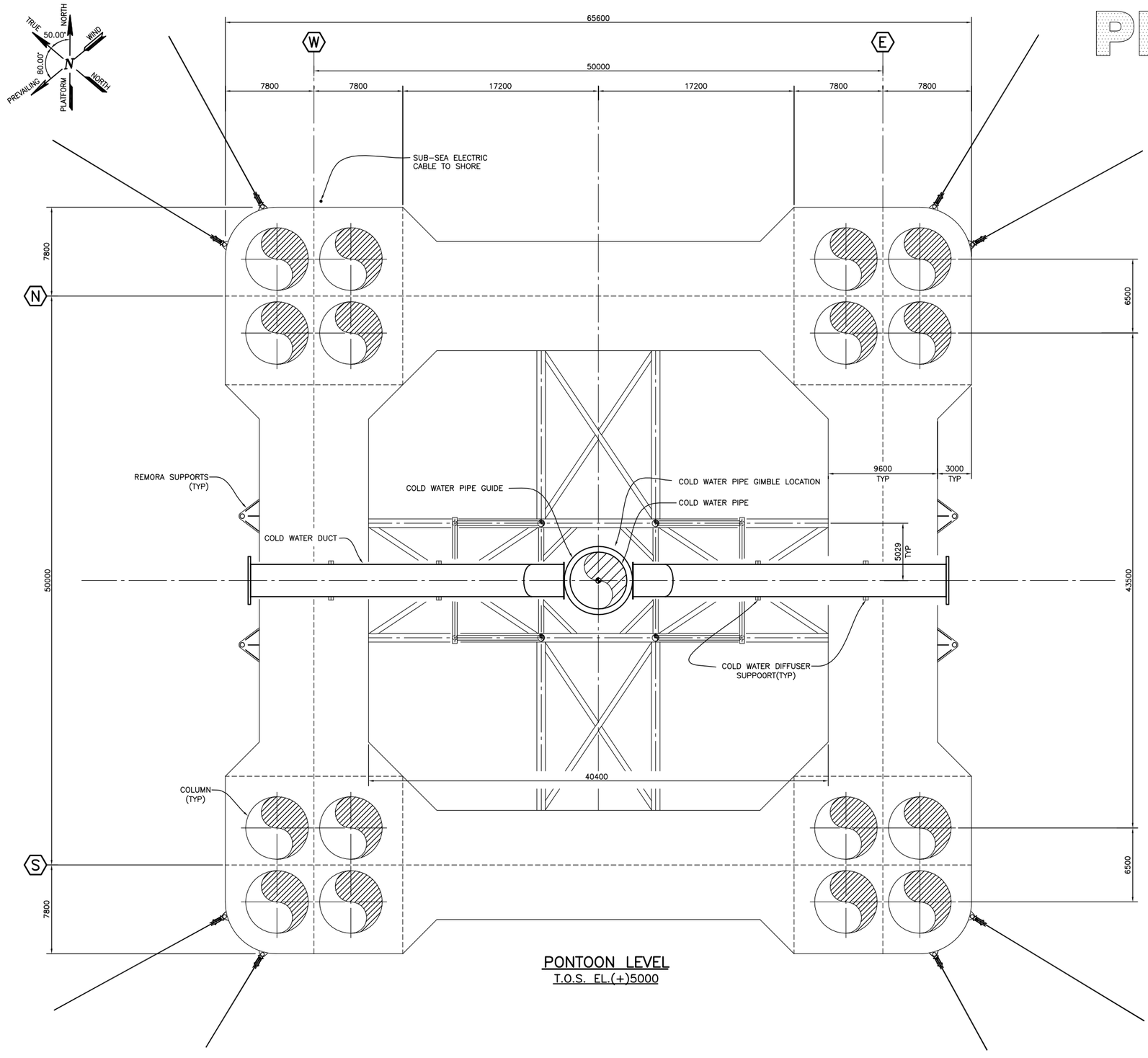
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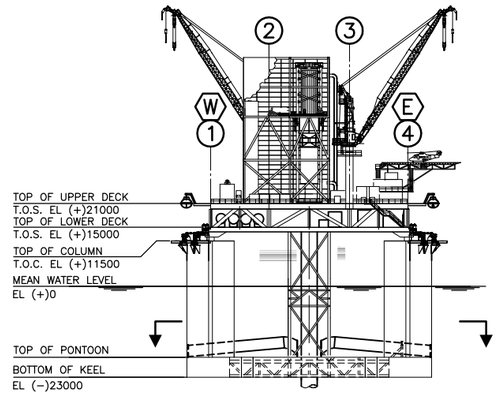
PRELIMINARY

A1 - 594 x 841

PRELIMINARY



PONTOON LEVEL
T.O.S. EL.(+)5000



KEY PLAN

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PRELIMINARY					
BIDDING					
MATL ORDER					
FABRICATION					

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OTEC CONCEPT
10 MEGAWATT PLATFORM

GENERAL ARRANGEMENT
PONTOON LEVEL
PLAN
(CWP FABRICATION/NO REMORAS)

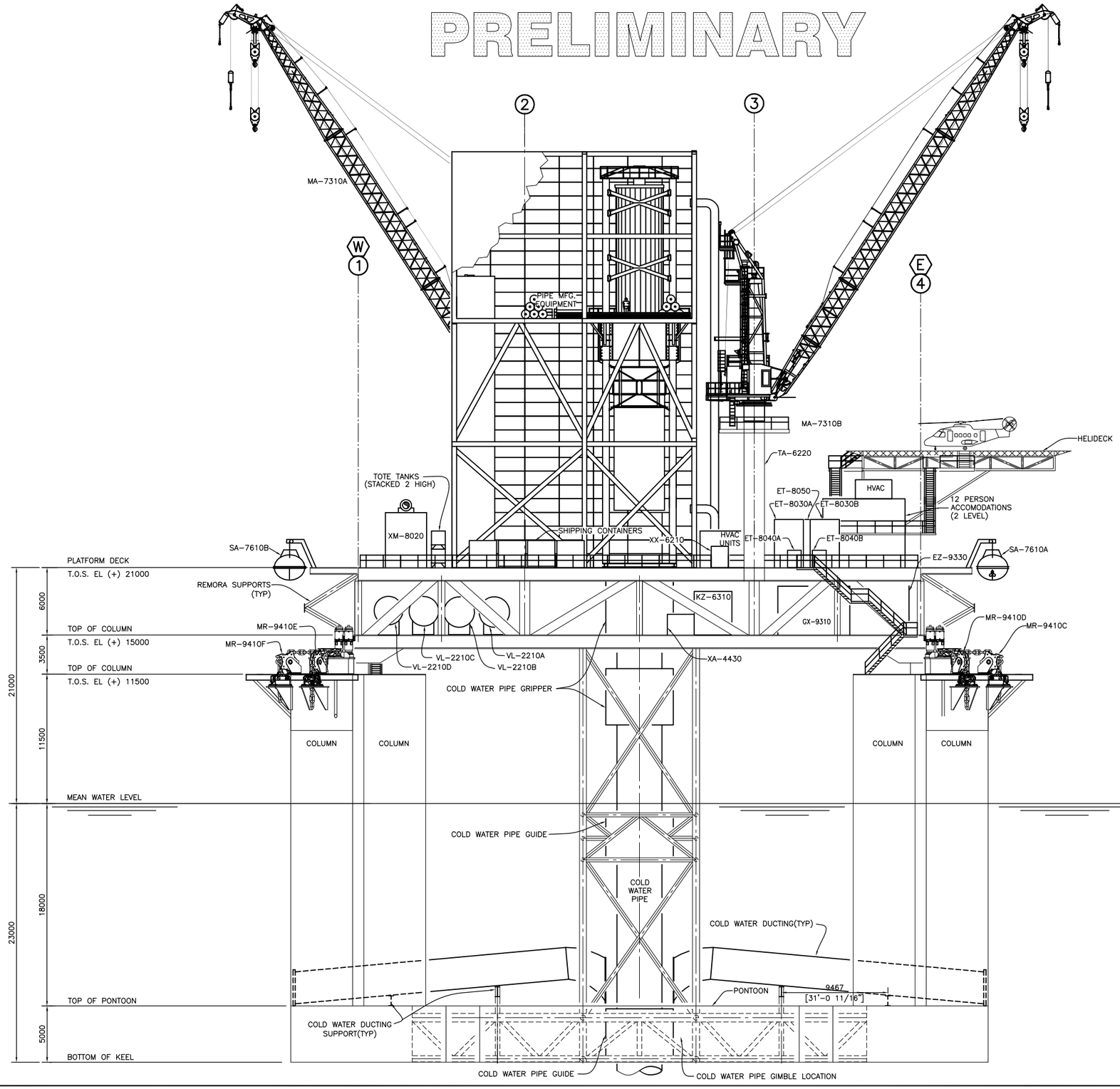
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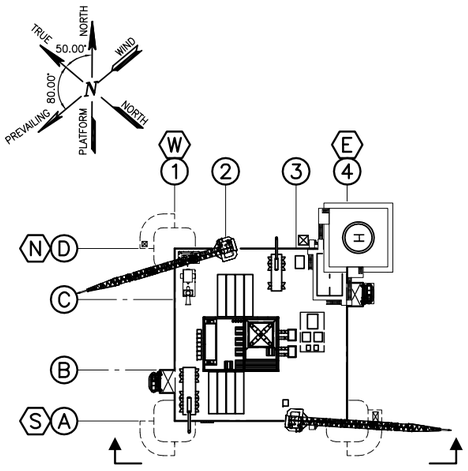
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A1 – 594 x 841

PRELIMINARY

TAG NO.	EQUIPMENT NAME
ET-8030A/B	13.8/4.16kV TRANSFORMER
ET-8040A/B	13.8/4.16kV TRANSFORMER
ET-8050	13.8/33kV SET UP TRANSFORMER
EZ-9330	MCC/SWGR/CTRL BUILDING
GX-9310	MCC ROOM AC PACKAGE
KZ-6310	AIR COMPRESSOR SKID
MA-7310A	PEDESTAL CRANE
MA-7310B	PEDESTAL CRANE
MR-9410C/D/E/F	MOORING EQUIPMENT
SA-7610A	SURVIVAL CRAFT
SA-7610B	SURVIVAL CRAFT
TA-6220	DIESEL STORAGE TANK
XA-4430	OILY WATER SEPARATOR
XM-8020	AUXILLARY DIESEL GENERATOR PACKAGE
XX-6210	DIESEL TRANSFER SKID
VL-2210A/B/C/D	AMMONIA STORAGE TANK





KEY PLAN

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BIDDING					
MATL ORDER					
FABRICATION					

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OTEC CONCEPT 10 MEGAWATT PLATFORM

GENERAL ARRANGEMENT LOOKING NORTH ELEVATION (CWP FABRICATION/NO REMORAS)

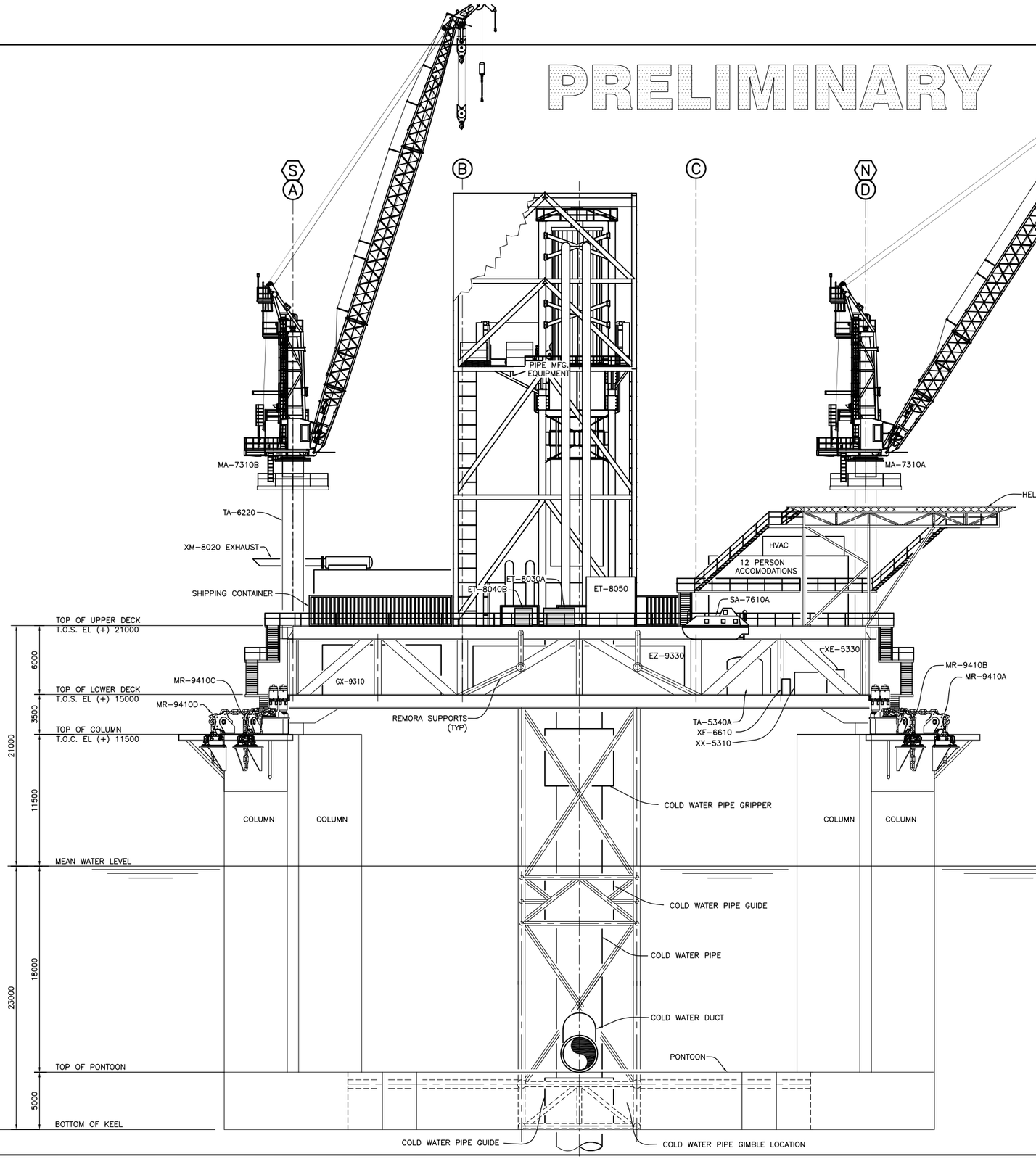
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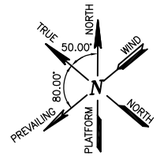
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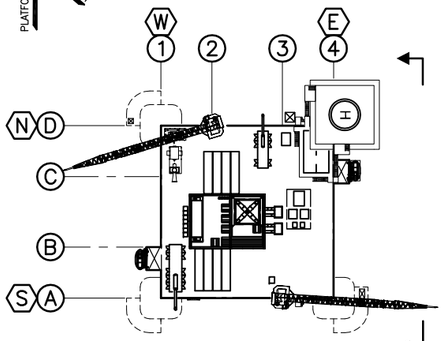
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PRELIMINARY

TAG NO.	EQUIPMENT NAME
ET-8030A/B	13.8/4.18kV TRANSFORMER
ET-8040A/B	13.8/4.16kV TRANSFORMER
ET-8050	13.8/33kV SET UP TRANSFORMER
EZ-9330	MCC/SWGR/CTRL BUILDING
GX-9310	MCC ROOM AC PACKAGE
MA-7310A	PEDESTAL CRANE
MA-7310B	PEDESTAL CRANE
MR-9410A/B/C/D	MOORING EQUIPMENT
SA-7610A	SURVIVAL CRAFT
TA-5340A	FRESH WATER STORAGE TANK
TA-6220	DIESEL STORAGE TANK
XE-5330	POTABLE WATER PRESSURE SET
XF-6610	SEWAGE TREATMENT PLANT
XM-8020	AUXILLARY DIESEL GENERATOR PACKAGE
XX-5310	FRESH WATER MAKER







KEY PLAN

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MATL ORDER					
FABRICATION					

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OTEC CONCEPT
10 MEGAWATT PLATFORM

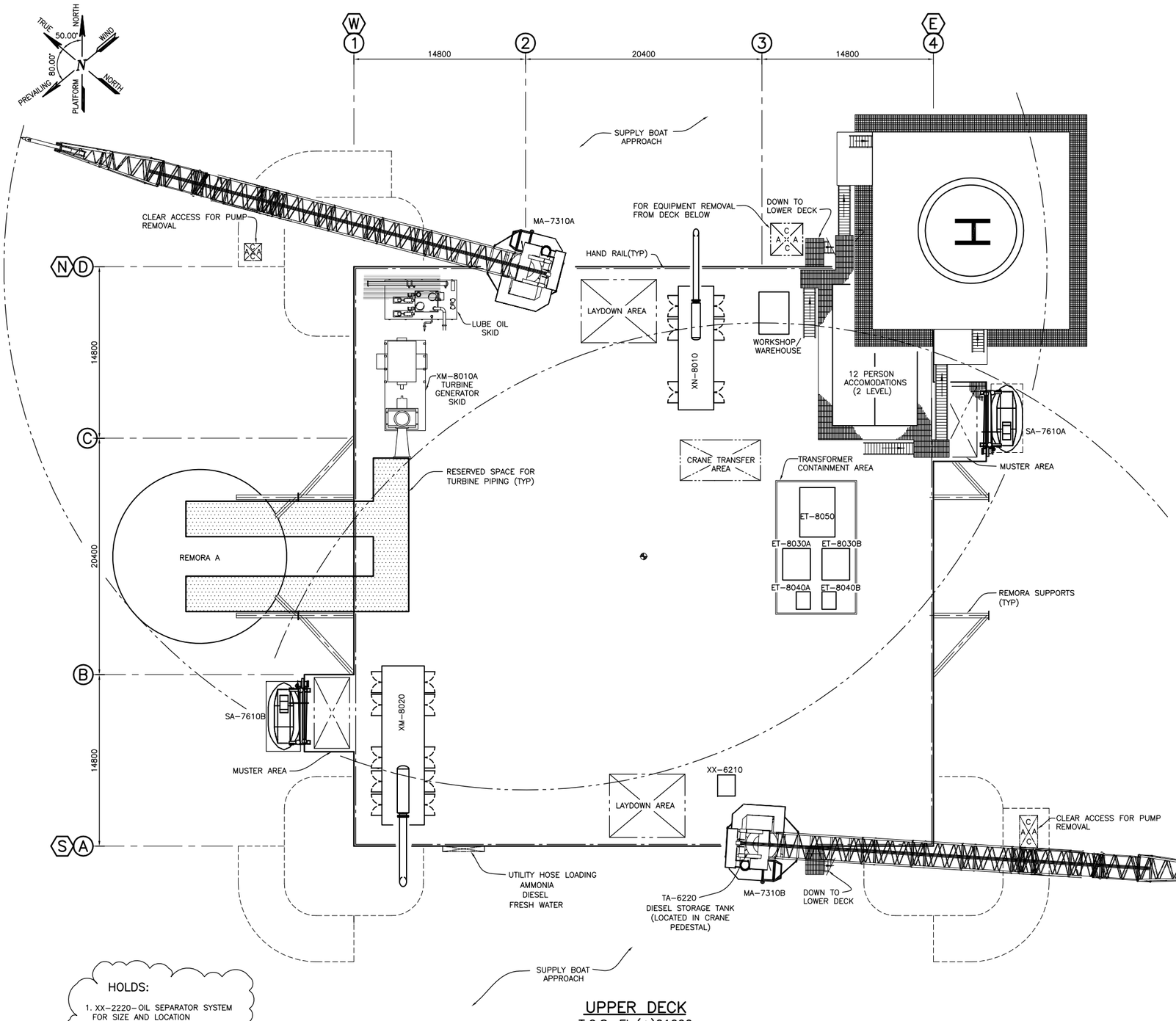
GENERAL ARRANGEMENT
LOOKING WEST
ELEVATION
(CWP FABRICATION/NO REMORAS)

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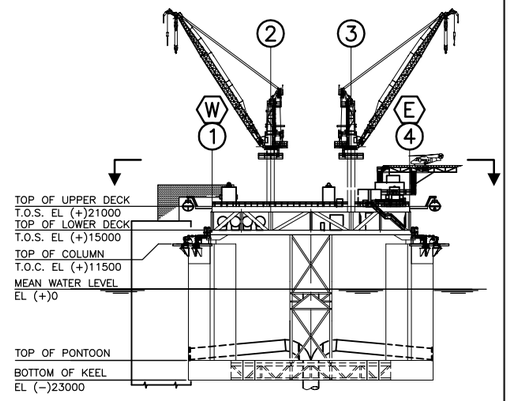
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A1 - 594 x 841

TAG NO.	EQUIPMENT NAME
ET–8030A/B	13.8/4.16kV TRANSFORMER
ET–8040A/B	13.8/4.16kV TRANSFORMER
ET–8050	13.8/33kV SET UP TRANSFORMER
MA–7310A	PEDESTAL CRANE
MA–7310B	PEDESTAL CRANE
SA–7610A	SURVIVAL CRAFT
SA–7610B	SURVIVAL CRAFT
TA–6220	DIESEL STORAGE TANK
XM–8010A	TURBINE GENERATOR
XM–8020	AUXILLARY DIESEL GENERATOR PACKAGE
XN–8010	EMERGENCY GENERATOR PACKAGE
XX–2220	OIL SEPARATOR SYSTEM
XX–6210	DIESEL TRANSFER SKID



UPPER DECK
T.O.S. EL.(+)21000



KEY PLAN

HOLDS:

1. XX–2220–OIL SEPARATOR SYSTEM FOR SIZE AND LOCATION

PRELIMINARY

REV	DESCRIPTION	BY	DATE
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OTEC CONCEPT 10 MEGAWATT PLATFORM

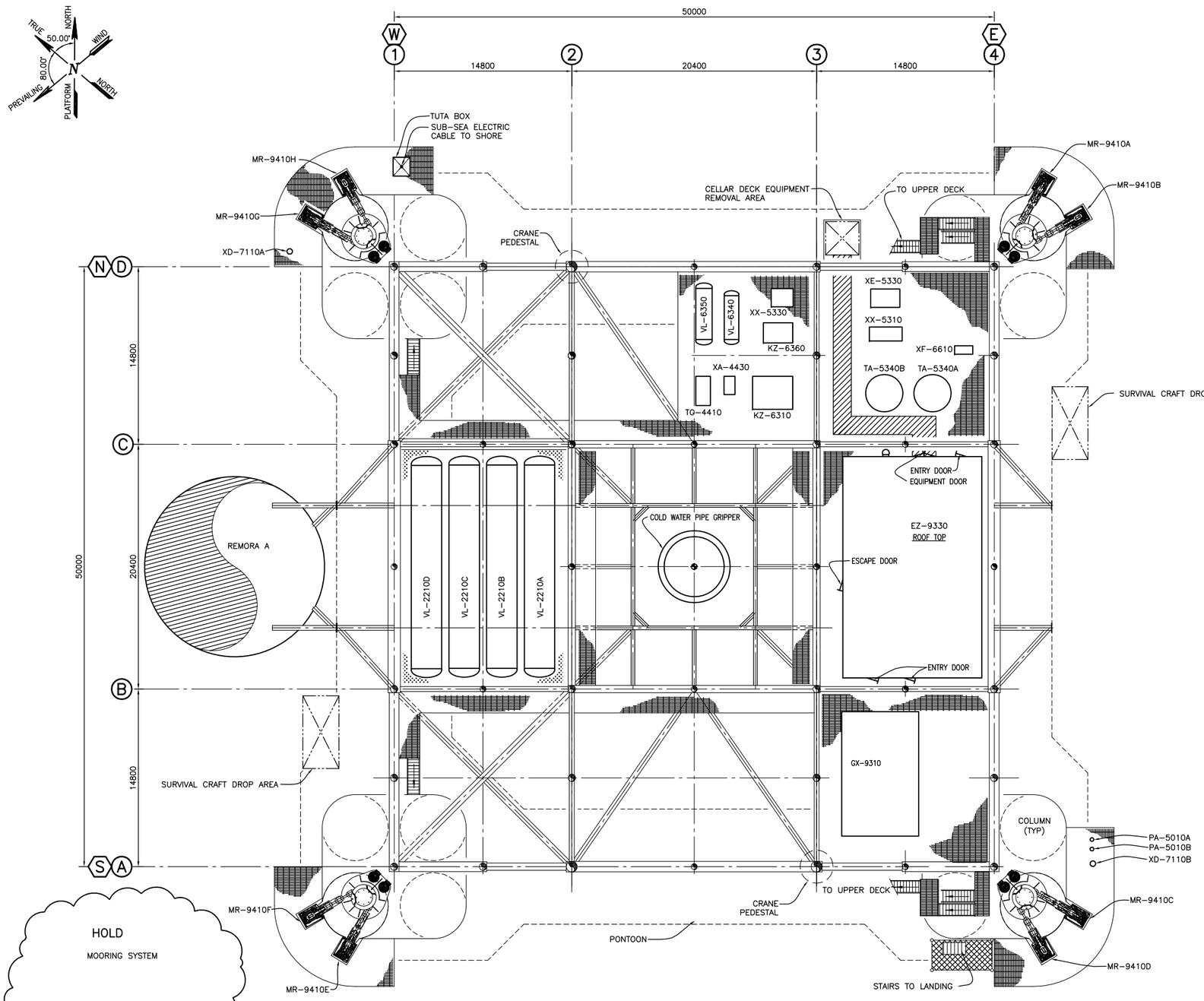
GENERAL ARRANGEMENT UPPER DECK PLAN (PILOT TEST/ONE REMORA)

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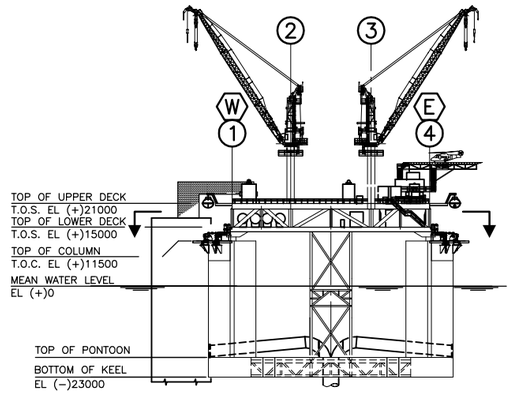
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A1 – 594 x 841

TAG NO.	EQUIPMENT NAME
EZ-9330	MCC/SWGR/CTRL BUILDING
GX-9310	MCC ROOM AC PACKAGE
KZ-6310	AIR COMPRESSOR SKID
KZ-6360	BLACK START AIR COMPRESSOR SKID
MR-9410A/B/C/D/E/F/G/H	MOORING EQUIPMENT
PA-5010A/B	SEAWATER LIFT PUMP
TA-5340A/B	FRESH WATER STORAGE TANK
TG-4410	TOPSIDES OILY WATER SUMP TANK
VL-2210A/B/C/D	AMMONIA STORAGE TANK
VL-6340	INSTRUMENT AIR RECIEVER
VL-6350	UTILITY AIR RECIEVER
XA-4430	OILY WATER SEPARATOR
XD-7110A/B	FIREWATER PUMP
XE-5330	POTABLE WATER PRESSURE SET
XF-6610	SEWAGE TREATMENT PLANT
XX-5310	FRESH WATER MAKER
XX-5330	WASHDOWN WATER SKID



LOWER DECK
T.O.S. EL.(+)15000



KEY PLAN

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OTEC CONCEPT
10 MEGAWATT PLATFORM

GENERAL ARRANGEMENT
LOWER DECK
PLAN
(PILOT TEST/ONE REMORA)

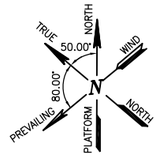
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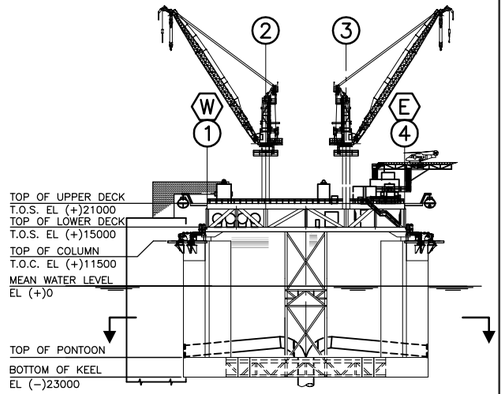
PRELIMINARY

A1 - 594 x 841

PRELIMINARY



PONTOON LEVEL
T.O.S. EL.(+)5000



KEY PLAN

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10 MEGAWATT PLATFORM

GENERAL ARRANGEMENT
PONTOON LEVEL
PLAN
(PILOT TEST/ONE REMORA)

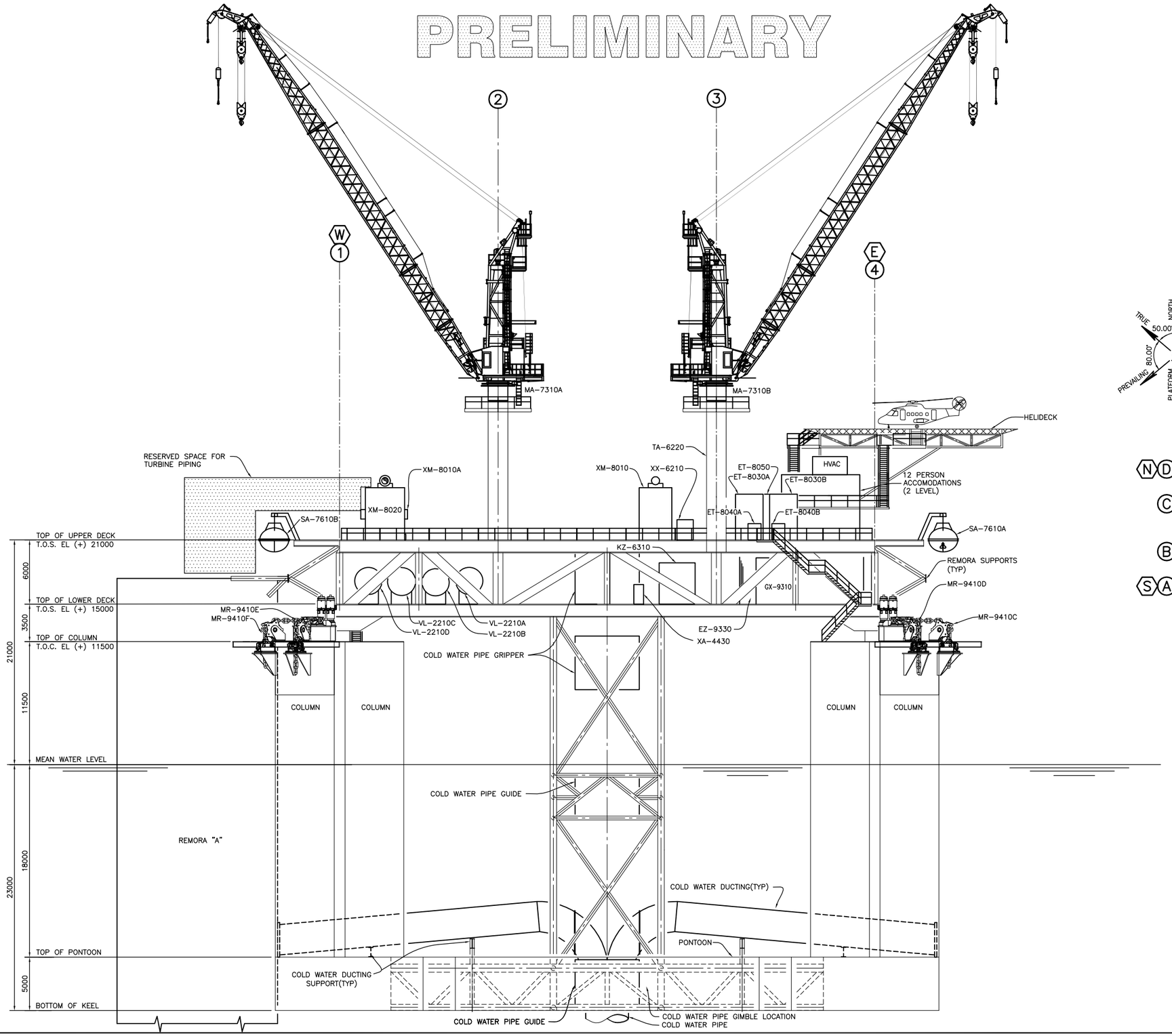
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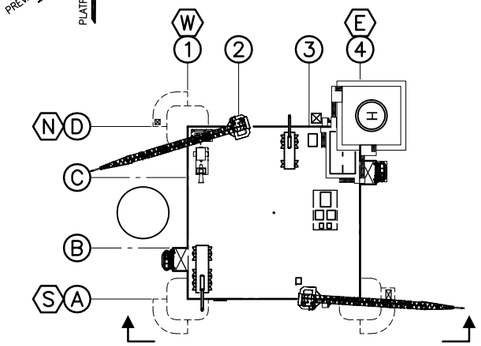
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A1 – 594 x 841

PRELIMINARY

TAG NO.	EQUIPMENT NAME
ET–8050	13.8/33kV SET UP TRANSFORMER
EZ–9330	MCC/SWGR/CTRL BUILDING
GX–9310	MCC ROOM AC PACKAGE
KZ–6310	AIR COMPRESSOR SKID
MA–7310A	PEDESTAL CRANE
MA–7310B	PEDESTAL CRANE
MR–9410C/D/E/F	MOORING EQUIPMENT
SA–7610A	SURVIVAL CRAFT
SA–7610B	SURVIVAL CRAFT
TA–6220	DIESEL STORAGE TANK
XA–4430	OILY WATER SEPARATOR
XM–8010A	TURBINE GENERATOR
XM–8020	AUXILLARY DIESEL GENERATOR PACKAGE
XN–8010	EMERGENCY GENERATOR PACKAGE
XX–6210	DIESEL TRANSFER SKID
VL–2210A/B/C/D	AMMONIA STORAGE TANK





KEY PLAN

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OTEC CONCEPT 10 MEGAWATT PLATFORM

GENERAL ARRANGEMENT LOOKING NORTH ELEVATION (PILOT TEST ONE REMORA)

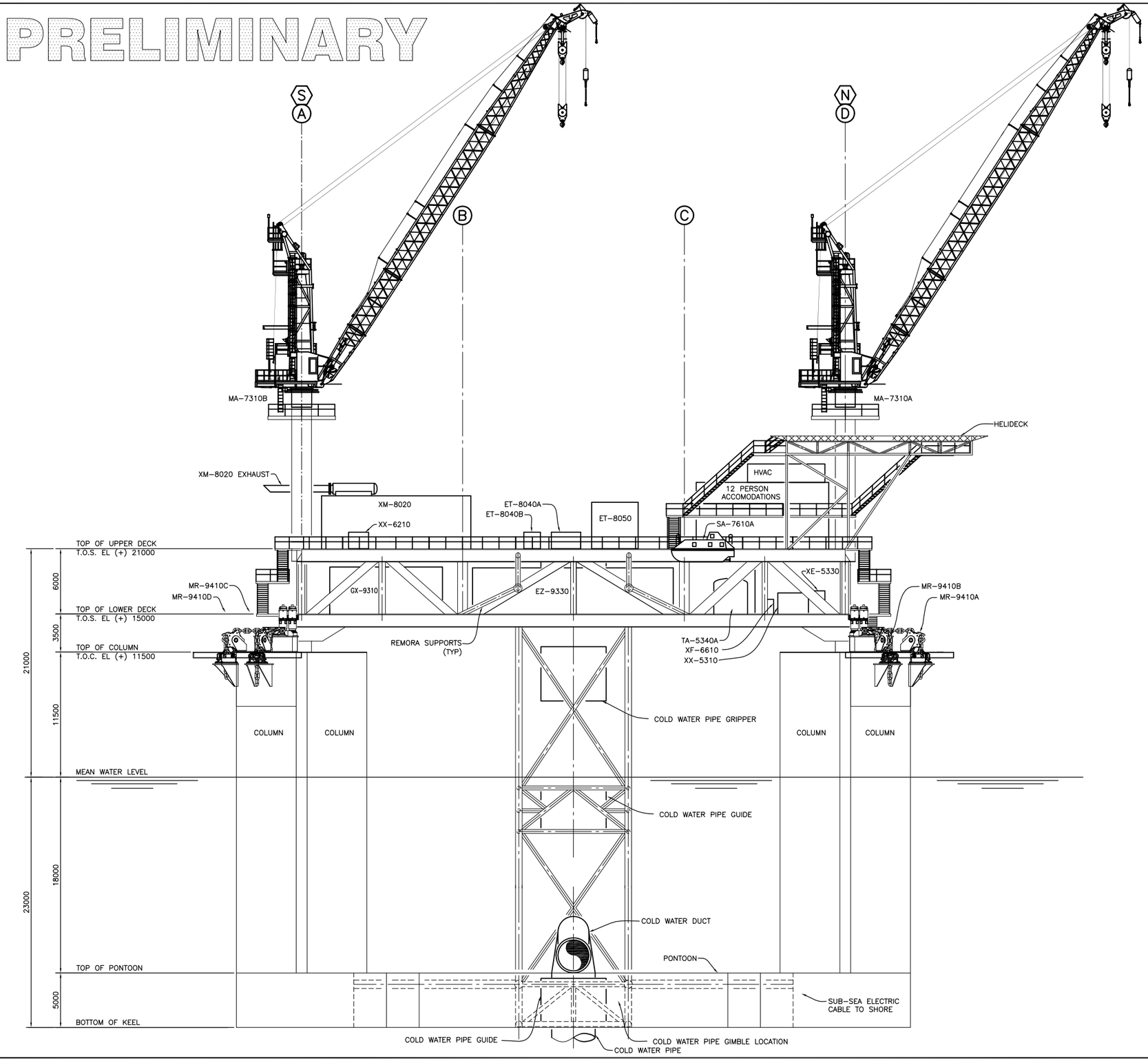
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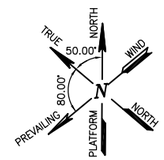
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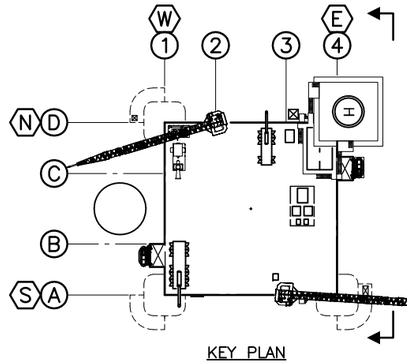
A1 – 594 x 841

PRELIMINARY

TAG NO.	EQUIPMENT NAME
ET–8030A/B	13.8/4.18kV TRANSFORMER
ET–8040A/B	13.8/4.16kV TRANSFORMER
ET–8050	13.8/33kV SET UP TRANSFORMER
EZ–9330	MCC/SWGR/CTRL BUILDING
GX–9310	MCC ROOM AC PACKAGE
MA–7310A	PEDESTAL CRANE
MA–7310B	PEDESTAL CRANE
MR–9410A/B/C/D	MOORING EQUIPMENT
SA–7610A	SURVIVAL CRAFT
TA–5340A	FRESH WATER STORAGE TANK
TA–6220	DIESEL STORAGE TANK
XE–5330	POTABLE WATER PRESSURE SET
XF–6610	SEWAGE TREATMENT PLANT
XM–8020	AUXILLARY DIESEL GENERATOR PACKAGE
XX–5310	FRESH WATER MAKER







KEY PLAN

REV	DESCRIPTION	BY	DATE
D	UPDATE	CEB	06/16/10
C	UPDATE	CEB	03/18/10
B	UPDATED	CEB	02/04/10
A	ISSUED FOR INFORMATION ONLY	CEB	02/20/09

RELEASE FOR:	DEPT ENGR	PROJ ENGR	DESIGN ENGR	DESIGN LEAD	DATE
PRELIMINARY					
BIDDING					
MATL ORDER					
FABRICATION					

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OTEC CONCEPT
10 MEGAWATT PLATFORM

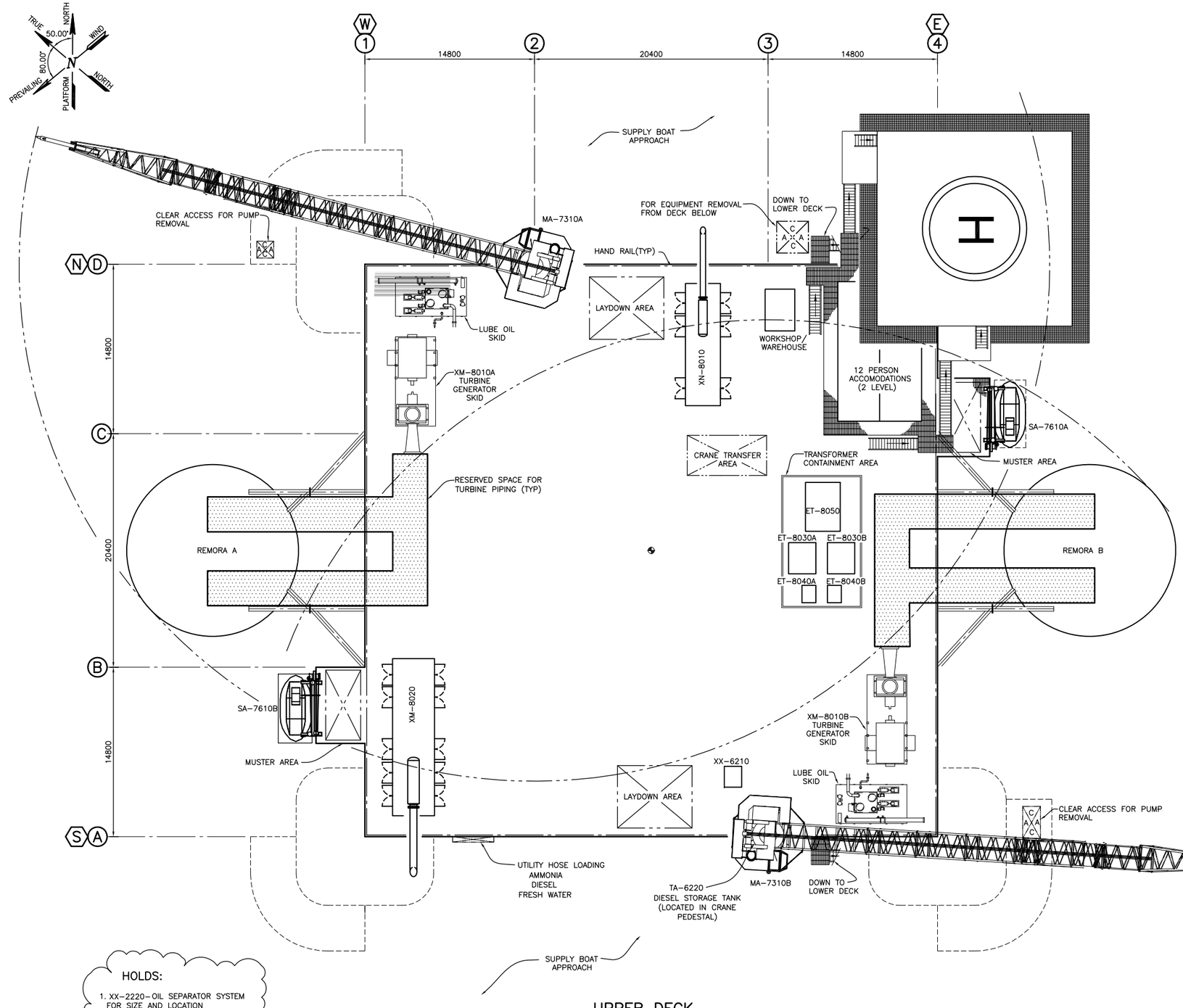
GENERAL ARRANGEMENT
LOOKING WEST
ELEVATION
(PILOT TEST ONE REMORA)

PROJ NO.	SCALE	DRAWN	DATE	CHECKED
H09117	1:175	CEB	02/20/09	

DWG NO.	SHT	REV
H09117–G–DWG–GN–1024	01	D

A1 – 594 x 841

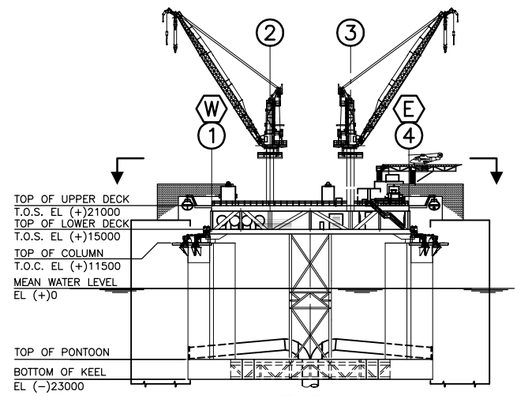
TAG NO.	EQUIPMENT NAME
ET–8030A/B	13.8/4.16kV TRANSFORMER
ET–8040A/B	13.8/4.16kV TRANSFORMER
ET–8050	13.8/33kV SET UP TRANSFORMER
MA–7310A	PEDESTAL CRANE
MA–7310B	PEDESTAL CRANE
SA–7610A	SURVIVAL CRAFT
SA–7610B	SURVIVAL CRAFT
TA–6220	DIESEL STORAGE TANK
XM–8010A	TURBINE GENERATOR
XM–8010B	TURBINE GENERATOR
XM–8020	AUXILLARY DIESEL GENERATOR PACKAGE
XN–8010	EMERGENCY GENERATOR PACKAGE
XX–2220	OIL SEPARATOR SYSTEM
XX–6210	DIESEL TRANSFER SKID



HOLDS:

1. XX–2220–OIL SEPARATOR SYSTEM FOR SIZE AND LOCATION

UPPER DECK
T.O.S. EL.(+)21000



KEY PLAN

PRELIMINARY

REV	DESCRIPTION	BY	DATE
D	UPDATED	CEB	06/16/10
C	UPDATED	CEB	03/18/10
B	UPDATED	CEB	02/04/10
A	ISSUED FOR INFORMATION ONLY	CEB	01/26/10

RELEASE FOR:	DEPT ENGR	PROJ ENGR	DESIGN ENGR	DESIGN LEAD	DATE
PRELIMINARY					
BIDDING					
MATL ORDER					
FABRICATION					

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OTEC CONCEPT 10 MEGAWATT PLATFORM

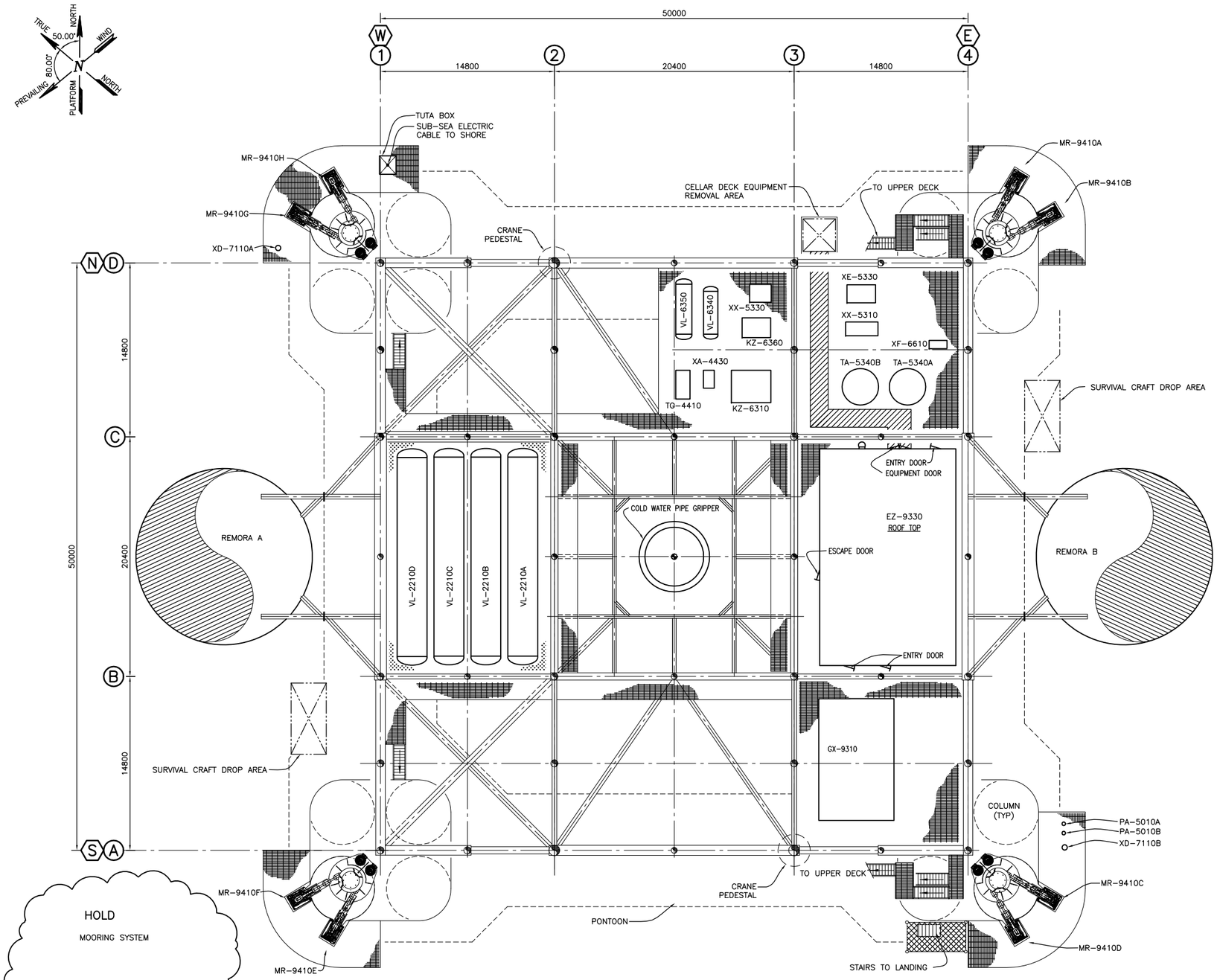
GENERAL ARRANGEMENT UPPER DECK PLAN (FULL PRODUCTION/TWO POWER UNITS)

PROJ NO.	SCALE	DRAWN	DATE	CHECKED
H09117	1:175	CEB	01/21/10	

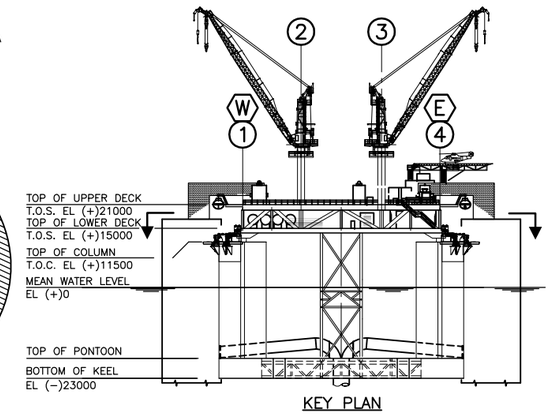
DWG NO.	SHT	REV
H09117–G–DWG–GN–1030	01	D

A1 – 594 x 841

TAG NO.	EQUIPMENT NAME
EZ-9330	MCC/SWGR/CTRL BUILDING
GX-9310	MCC ROOM AC PACKAGE
KZ-6310	AIR COMPRESSOR SKID
KZ-6360	BLACK START AIR COMPRESSOR SKID
MR-9410A/B/C/D/E/F/G/H	MOORING EQUIPMENT
PA-5010A/B	SEAWATER LIFT PUMP
TA-5340A/B	FRESH WATER STORAGE TANK
TG-4410	TOPSIDES OILY WATER SUMP TANK
VL-2210A/B/C/D	AMMONIA STORAGE TANK
VL-6340	INSTRUMENT AIR RECIEVER
VL-6350	UTILITY AIR RECIEVER
XA-4430	OILY WATER SEPARATOR
XD-7110A/B	FIREWATER PUMP
XE-5330	POTABLE WATER PRESSURE SET
XF-6610	SEWAGE TREATMENT PLANT
XX-5310	FRESH WATER MAKER
XX-5330	WASHDOWN WATER SKID



LOWER DECK
T.O.S. EL.(+)15000



KEY PLAN

PRELIMINARY

REV	DESCRIPTION	BY	DATE
D	UPDATED	CEB	06/16/10
C	UPDATED	CEB	03/18/10
B	UPDATED	CEB	02/04/10
A	ISSUED FOR INFORMATION ONLY	CEB	01/26/10

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PRELIMINARY					
BIDDING					
MATL ORDER					
FABRICATION					

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Houston Offshore ENGINEERING

OTEC CONCEPT
10 MEGAWATT PLATFORM

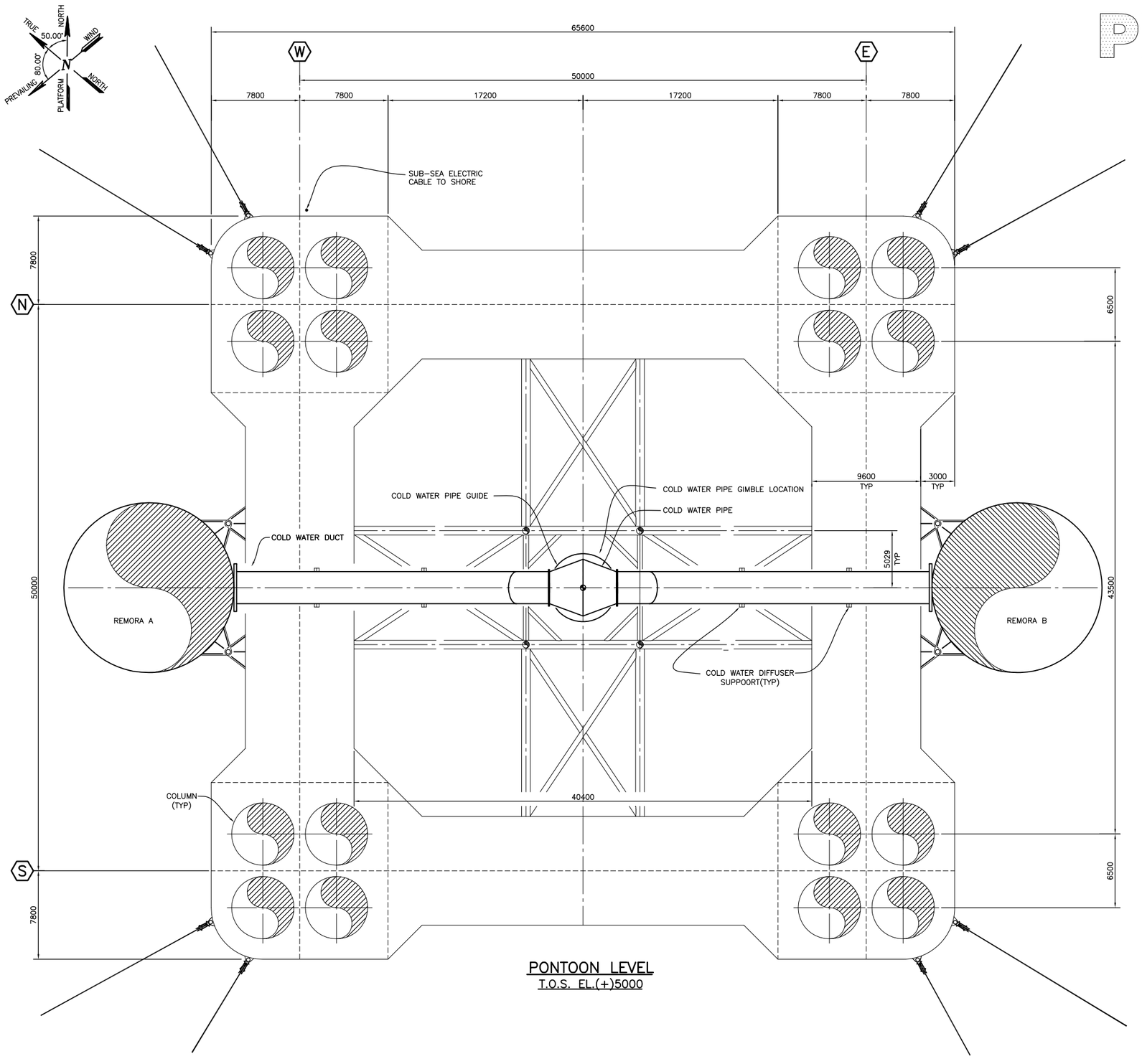
GENERAL ARRANGEMENT
LOWER DECK
PLAN
(FULL PRODUCTION/TWO POWER UNITS)

PROJ NO.	SCALE	DRAWN	DATE	CHECKED
H09117	1:175	CEB	02/19/09	

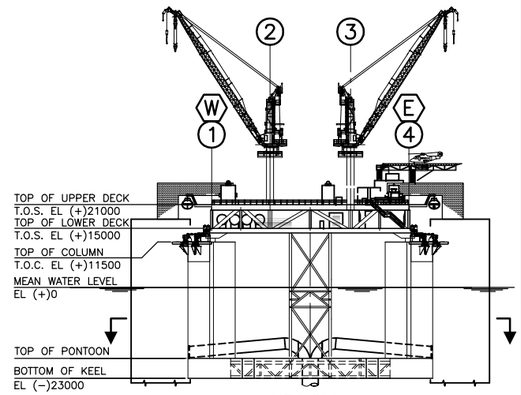
DWG NO.	SHT	REV
H09117-G-DWG-GN-1031	01	D

A1 - 594 x 841

PRELIMINARY



PONTOON LEVEL
T.O.S. EL.(+)5000



KEY PLAN

REV	DESCRIPTION	BY	DATE
D	UPDATE	CEB	06/16/10
C	UPDATED	CEB	03/18/10
B	UPDATED	CEB	03/18/10
A	ISSUED FOR INFORMATION ONLY	CEB	02/19/09

RELEASE FOR:	DEPT ENGR	PROJ ENGR	DESIGN ENGR	DESIGN LEAD	DATE
PRELIMINARY					
BIDDING					
MATL ORDER					
FABRICATION					

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OTEC CONCEPT
10 MEGAWATT PLATFORM

GENERAL ARRANGEMENT
PONTOON LEVEL
PLAN
(FULL PRODUCTION/TWO POWER UNITS)

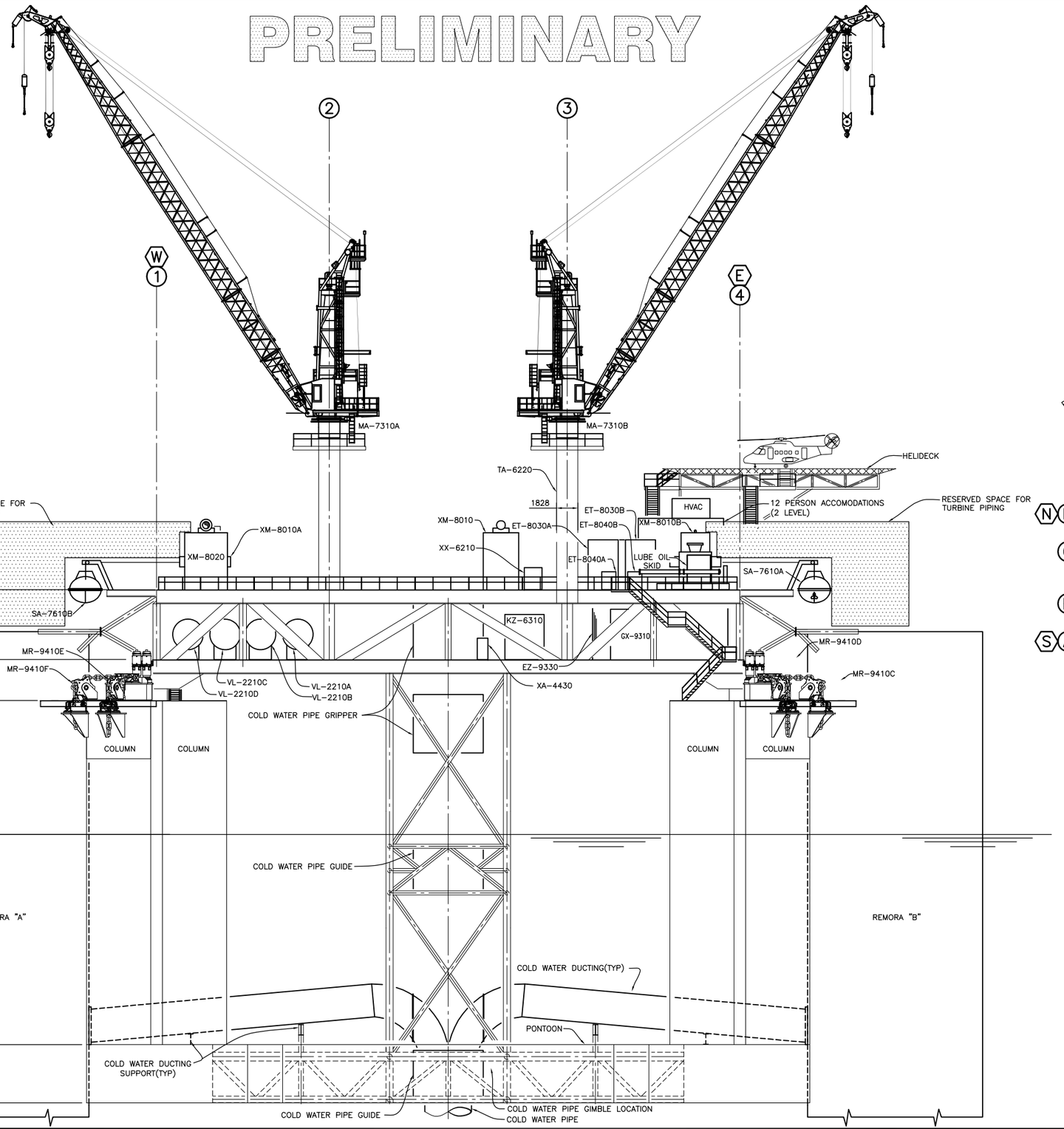
PROJ NO.	SCALE	DRAWN	DATE	CHECKED
H09117	1:175	CEB	02/19/09	

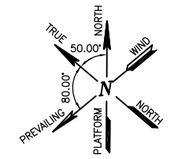
DWG NO.	SHT	REV
H09117-G-DWG-GN-1032	01	D

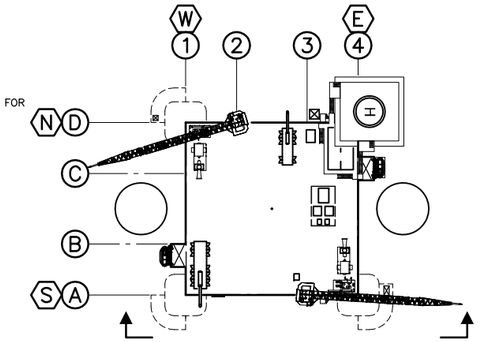
A1 - 594 x 841

PRELIMINARY

TAG NO.	EQUIPMENT NAME
ET–8050	13.8/33kV SET UP TRANSFORMER
EZ–9330	MCC/SWGR/CTRL BUILDING
GX–9310	MCC ROOM AC PACKAGE
KZ–6310	AIR COMPRESSOR SKID
MA–7310A	PEDESTAL CRANE
MA–7310B	PEDESTAL CRANE
MR–9410C/D/E/F	MOORING EQUIPMENT
SA–7610A	SURVIVAL CRAFT
SA–7610B	SURVIVAL CRAFT
TA–6220	DIESEL STORAGE TANK
XA–4430	OILY WATER SEPARATOR
XM–8010A	TURBINE GENERATOR
XM–8010B	TURBINE GENERATOR
XM–8020	AUXILLARY DIESEL GENERATOR PACKAGE
XN–8010	EMERGENCY GENERATION PACKAGE
XX–6210	DIESEL TRANSFER SKID
VL–2210A/B/C/D	AMMONIA STORAGE TANK







KEY PLAN

REV	DESCRIPTION	BY	DATE
D	UPDATE	CEB	06/16/10
C	UPDATE	CEB	03/18/10
B	UPDATED	CEB	02/04/10
A	ISSUED FOR INFORMATION ONLY	CEB	02/20/09

RELEASE FOR:	DEPT ENGR	PROJ ENGR	DESIGN ENGR	DESIGN LEAD	DATE
PRELIMINARY					
BIDDING					
MATL ORDER					
FABRICATION					

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OTEC CONCEPT 10 MEGAWATT PLATFORM

GENERAL ARRANGEMENT LOOKING NORTH ELEVATION (FULL PRODUCTION/TWO POWER UNITS)

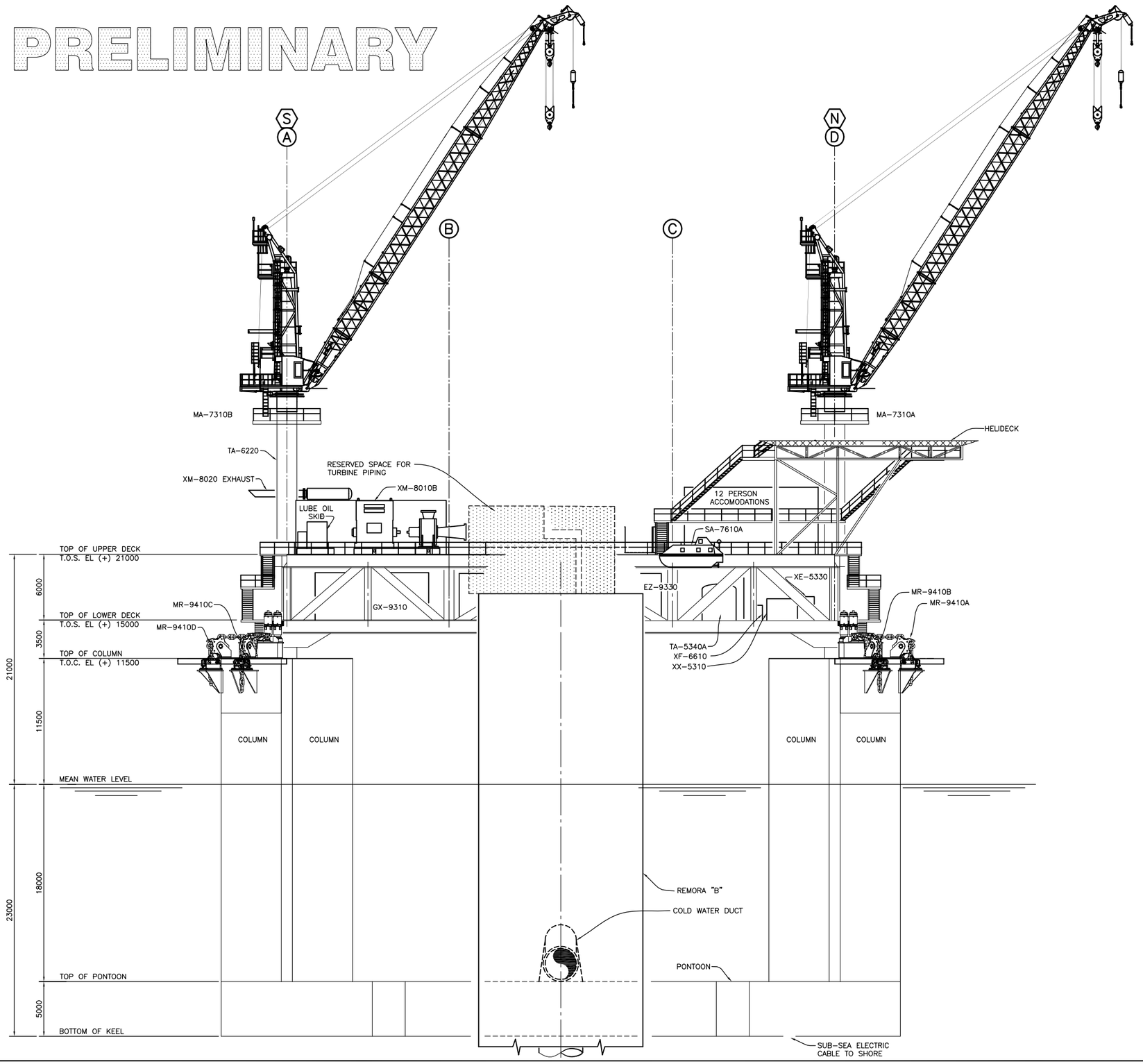
PROJ NO.	SCALE	DRAWN	DATE	CHECKED
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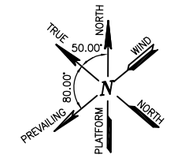
DWG NO.	SHT	REV
H09117–G–DWG–GN–1033	01	D

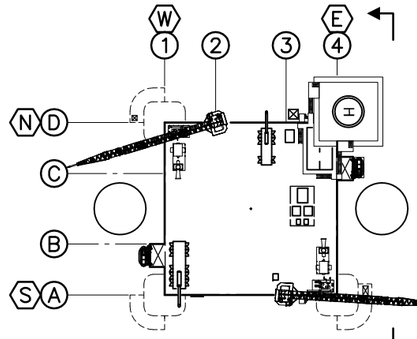
A1 – 594 x 841

PRELIMINARY

TAG NO.	EQUIPMENT NAME
ET–8050	13.8/33kV SET UP TRANSFORMER
ET–8040A/B	13.8/4.16kV TRANSFORMER
EZ–9330	MCC/SWGR/CTRL BUILDING
GX–9310	MCC ROOM AC PACKAGE
MA–7310A	PEDESTAL CRANE
MA–7310B	PEDESTAL CRANE
MR–9410A/B/C/D	MOORING EQUIPMENT
SA–7610A	SURVIVAL CRAFT
TA–5340A	FRESH WATER STORAGE TANK
TA–6220	DIESEL STORAGE TANK
XE–5330	POTABLE WATER PRESSURE SET
XF–6610	SEWAGE TREATMENT PLANT
XM–8010B	TURBINE GENERATOR
XX–5310	FRESH WATER MAKER







KEY PLAN

REV	DESCRIPTION	BY	DATE
D	UPDATE	CEB	06/16/10
C	UPDATE	CEB	03/18/10
B	UPDATED	CEB	02/04/10
A	ISSUED FOR INFORMATION ONLY	CEB	02/20/09

RELEASE FOR:	DEPT ENGR	PROJ ENGR	DESIGN ENGR	DESIGN LEAD	DATE
PRELIMINARY					
BIDDING					
MATL ORDER					
FABRICATION					

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OTEC CONCEPT
10 MEGAWATT PLATFORM

GENERAL ARRANGEMENT
LOOKING WEST
ELEVATION
(FULL PRODUCTION/TWO POWER UNITS)

PROJ NO.	SCALE	DRAWN	DATE	CHECKED
H09117	1:175	CEB	02/20/09	

DWG NO.	SHT	REV
H09117–G–DWG–GN–1034	01	D

A1 – 594 x 841

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-2
Platform Master Equipment List
OTEC-2010-001

17 September 2010

Prepared for:

Naval Facilities Engineering Command
Naval Facilities Engineering Service Center (NFESC)
1100 23rd Avenue
Port Hueneme, CA 93043-4370
Attn: Mr. Brian Cable, Contracting Officer Representative

Prepared by:

Lockheed Martin MS2
9500 Godwin Drive
Manassas, VA 20110

Distribution Statement A: Approved for public release; distribution is unlimited

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TOPSIDES MAJOR EQUIPMENT LIST

LOCKHEED MARTIN

Client: Lockheed Martin
Project: NAFAC OTEC Platform Pre-FEED
Location: Hawaii
Project No: H09117
Document No.: H09117-T-LST-GL-15000

Rev	Date	Description	By	Chk	Appv
A	1/27/2010	Issued for Information	PAK		NWL
B	6/25/2010	Issued for Information	NSJ	PAK	NWL

Basic Units	
Pressure	barg
Temperature	ºC
Weight	Metric Tonne
Dimensions	millimeter
Capacity	cu. meter

1.- Dimensions & Weights are estimated for each individual skid
2.- Weights are without contingency

Rev	Tag Number		Description	QTY	%	Nominal Capacity/ Duty	Dimensions (Notes 1 & 2)				Weight (Notes 1 & 2) (MT)				Manufacturer & Model	Remarks
	Eq	Number					OD (mm)	Length S/S L (mm)	Width W (mm)	Height H (mm)	Dry Each	Dry Total	Operating Each	Operating Total		
22 - AMMONIA																
B	VL	2210	Ammonia Storage Tank	4	25%	87 cu. Meters	2500	16900			29.3	**117.2**	62	**248**	Butcher's Welding and Fabricating Service	
B	XX	2220	Oil Separator System	1	100%											
44 - OILY WATER																
	TG	4410	Topsides Oily Water Sump Tank	1	100%	3.78 cu. meters		2400	1200	1200	2.1	**2.1**	4.2	**4.2**	Butcher's Welding and Fabricating Service	
	XA	4430	Oily Water Separator	1	100%	2.3 m3/hr		1500	900	1800	2.0	**2.0**	2.2	**2.2**	Specific Equipment - GREEN MARINE BOSS 11T / 107	
50 - SEAWATER																
B	PA	5010	Seawater Lift Pump	2	100%	340 m3/jhr @ 8.9 barg		500	500	900	4.5	**9**	5.5	**11**	S & N Pump - EMU NK-82-4+NU801-2135	
B	XE	5020	Sanitary Water Pressure Set	1		7.9 m3/hr @ 6.9 barg		2400	1500	2100	2.3	**2.3**	2.3	**2.3**	Specific Equipment SW-160 200	
53 - FRESH WATER																
	XX	5310	Fresh Water Maker	1	100%	15 c. meters / day		2700	1200	1900	1.8	**1.8**	1.98	1.98	CTREAT - ROUSTABOUT 10	
	XE	5330	Potable Water Pressure Set	1		7.9 m3/hr @ 6.9 barg		2400	1500	2100	1.4	**1.4**	2.3	**2.3**	Specific Equipment PW-160 200	
	TA	5340	Fresh Water Storage Tank	2	100%	19.3 cu. meters	3000			3200	0.7	**1.4**	19.9	**39.8**	POLY-CORR 1005100	
	XX	5350	Washdown Water Skid	1	100%	0.68 m3/hr @ 240 barg		1800	1500	1800	1.8	**1.8**	1.9	**1.9**		
62 - DIESEL																
	XX	6210	Diesel Transfer Skid	1	100%	10 m3/hr@ XX bar		1800	1200	1200	2.7	**2.7**	3.0	**3**	Specific Equipment based on 45 GPM	
B	TA	6220	Diesel Storage Tank	2	100%	37 cu. meters	2700			9100			43.0	**86**	**Weight of fuel In Crane Pedestal**	
63 - COMPRESSED AIR																
	KZ	6310	Air Compressor Skid	1	100%	424 m3/hr		3400	2700	3900	9.0	**9.0**	9.0	**9.0**	AIR DYNE	
	VL	6340	Instrument Air Receiver	1	100%	4 cu. meters	1200	3600			3.0	**3.0**	3.2	**3.2**	General Air Products	
B	VL	6350	Utility Air Receiver	1	100%	7.4 cu. meters	1500	4800			3.8	**3.8**	4.0	**4.0**	General Air Products	
	KZ	6360	Black Start Air Compressor Skid	1	100%	212 m3/hr		2400	1700	1800	2.7	**2.7**	2.7	**2.7**	AIR DYNE	
66 - SEWAGE TREATMENT																
	XF	6610	Sewage Treatment Plant	1	100%	1.14 cu. meters		1500	700	1300	0.9	**0.9**	1.6	**1.6**	Green Marine - FAST MX1	
71- FIREWATER																
	XD	7110	Firewater Pump Package	2	100%	114 m3/hr @ 105 barg		2500	600	1900	1.1	**2.2**	1.1	**2.2**	S&N Pump - Model 12L 55, 5 stg Pump	
73 - MATERIAL HANDLING																
	MA	7310	Pedestal Crane	2	100%	45 t @ 15 m (dynamic)		45 m Boom			85.7	**171.4**	90.0	**180.0**	SEATRAX 72 MODEL S7226 with 140 m or 150m boom	
76 - SAFETY EQUIPMENT																
	SA	7610	Survival Craft	2	100%	25 man		600	3000		5.5	**11.0**	4.5	**9.0**	RYAN CRAFT BH-7A with BDO 75 lauching Davit	
	SA	7620	Rescue Craft	1	100%			6700	2400		3.2	**3.2**	2.2	**2.2**	BH - HR6 With BD RBD 966 Fixed Davit	
77 - NAVIGATION AIDS																
	EI	7710	Aids to Navigation	1	100%		257			500	0.3	**0.3**	1.8	**1.8**	Tideland Navaid System	
	EI	7720	Foghorn	1	100%		800	800		2737	0.2	**0.2**	0.5	**0.5**	Tideland Navaid System	
80 - MAIN POWER 13.8 KV																
	XM	8010	Turbine Generator Package	2	50%	10 MVA		16500	7600	6000	35.0	**70.0**	38.5	**77.0**	GE FRAME 130 (2 X 7 - 9 MW)	1 Future.
	XM	8020	Auxiliary Diesel Generator Package	1	100%	3.1 MVA		13700	3000	4800	54.0	**54.0**	59.4	**59.4**	CATERPILLAR C175	
	ET	8030	13.8 / 4.16 kV Transformer	2	50%	5 MVA		2438	2743	2438	13.8	**27.6**	15.2	**30.4**	ABB - VA TRANSFORMER	1 Future
	ET	8040	13.8 / .48 kV Transformer	2	50%	0.5 MVA		1219	1524	1530	5.2	**10.4**	5.7	**11.4**	ABB - VA TRANSFORMER	1 Future

Houston Offshore ENGINEERING

TOPSIDES MAJOR EQUIPMENT LIST

LOCKHEED MARTIN

Client:	**Lockheed Martin**
Project:	**NAFAC OTEC Platform Pre-FEED**
Location:	**Hawaii**
Project No:	**H09117**
Document No.:	**H09117-T-LST-GL-15000**

Rev	Date	Description	By	Chk	Appv
A	1/27/2010	Issued for Information	PAK		NWL
B	6/25/2010	Issued for Information	NSJ	PAK	NWL

Basic Units	
Pressure	barg
Temperature	ºC
Weight	Metric Tonne
Dimensions	millimeter
Capacity	cu. meter

1.- Dimensions & Weights are estimated for each individual skid

2.- Weights are without contingency

Rev	Tag Number		Description	QTY	%	Nominal Capacity/ Duty	Dimensions (Notes 1 & 2)				Weight (Notes 1 & 2) (MT)				Manufacturer & Model	Remarks
											Dry		Operating			
	Eq	Number					OD (mm)	Length S/S L (mm)	Width W (mm)	Height H (mm)	Each	Total	Each	Total		
	ET	8050	13.8 / 33 kV Step-up Transformer	1	100%	20 MVA		4267	6096	6096	37.4	**37.4**	41.1	**41.1**	ABB - VA TRANSFORMER	
	LT	8060	Topsides Umbilical Termination Unit	1	100%											
	ET	8070	1000 HP VFD For CW and WW Pumps	4	100%	1000 HP VFD FOR EACH REMORA					2.0	**8.0**	2.0	**8.0**	ABB - 1000 HP VFD'S	
	ET	8070	300 HP VFD For Each Remora	4	100%	1000 HP VFD FOR EACH REMORA					0.6	**2.4**	0.6	**2.4**	ABB - 300 HP VFD'S	
	ET	8080	300 HP VFD For Winch Motors	2	100%	300 HP VFD FOR WINCH MOTORS					0.6	**1.2**	0.6	**1.2**	ABB - 300 HP VFD'S	
84 - EMERGENCY POWER 480V																
	XN	8010	Emergency Generator Package	1	100%	750 kVA		10700	3000	3600	20.5	**20.5**	22.6	**22.6**	CATERPILLAR 3508B.	
93 - BUILDINGS																
	AZ	9310	Living Quarters	1	100%	12 person		12000	7600	6000	98.0	**98.0**	107.8	**107.8**	Delta Engr (Delcor)	
	AZ	9320	Workshop / Warehouse	1	100%			12000	3000	2600	25.0	25.0	26.3	26.3	LQT	
	EZ	9330	MCC/SWGR/CTRL Building	1	100%			18500	11500	4800	166.0	**166.0**	166.0	**166.0**	POWELL	
97 - HVAC																
	GX	9310	MCC Room AC Package	1	100%	908400 BTU/h		10000	6500	4300	28.5	**28.5**	28.5	**28.5**	DWD AHU-73.1 Included in Powells Pricing)	
14 - HELIDECK																
	H		Helideck	1	100%	PER CAP 437		17000	17000		17.3	**17.3**	17.3	**17.3**	Delta Engr (Delcor)	
	H		Helideck - Stairs, Landing and Frame Support (Optional)	1	100%						8	8.0	8.0	8.0	TBD	
												912		**1,215**		

NOTES

All equipment sizing is preliminary for weight estimating purposes only.

Excluding:

Pedestal Crane Tank Dry Weight

Houston Offshore ENGINEERING

HULL MAJOR EQUIPMENT LIST

LOCKHEED MARTIN

Client:	Lockheed Martin
Project:	NAFAC OTEC Platform Pre-FEED
Location:	Hawaii
Project No:	H09117
Document No.:	H09117-H-LST-GL-15001

Rev	Date	Description	By	Chk	Appv
A	1/27/2010	Issued for Information	PAK		NWL
B	6/25/2010	Issued for Information	NSJ	PAK	NWL

Basic Units	
Pressure	barg
Temperature	ºC
Weight	Metric Tonne
Dimensions	millimeter
Capacity	cu. meter

1.- Dimensions & Weights are estimated for each individual skid
2.- Weights are without contingency

Rev	Tag Number		Description	QTY	%	Nominal Capacity/ Duty	Dimensions (Notes 1 & 2)				Weight (Notes 1 & 2) (MT)				Manufacturer & Model	Remarks
											Dry		Operating			
	Eq	Number					O. Dia (mm))	Length S/S L (mm)	Width W (mm)	Height H (mm)	Each (MT)	Total (MT)	Each (MT)	Total (MT)		
44 - OILY WATER																
	TG	4420	Hull Oily Water Sump Tank	4	100%	TBD					0.5	**2.0**	0.5	**2.0**		Weights are In-House estimates
	PA	4440	Hull Oily Water Sump Pump	4	100%	TBD					0.9	**3.6**	0.1	**0.5**	Goulds	Weights are In-House estimates
52 - BILGE AND BALLAST																
	PA	5210	Ballast Pump	4	100%	182 m3/hr @ 4.8 barg					0.8	**3.3**	1.6	**6.4**	S&N	
	PA	5220	Bilge Pump	4	100%	TBD					0.1	**0.3**	0.1	**0.3**	Wilden	Weights are In-House estimates
	PF	5230	Stripping Pump	4	100%	TBD					0.1	**0.3**	0.2	**0.7**	Wilden	Weights are In-House estimates
93 - BUILDINGS																
	AZ	9340	Hull E&I Room	4	100%						0	**0**	0	**0**	Included in the Topsides MCC Bldg	Weights are In-House estimates
94 - MOORING																
	MR	9410	Mooring Winch	4	100%	3557 kN @ 1m/min					2.2	**8.8**	2.2	**8.8**	Rolls - Royce	
	YX	9430	Deck Sheave, Vertical	12	100%						1.0	**12.0**	1.0	**12.0**		Weights are In-House estimates
	YX	9440	Underwater Fairlead	12	100%	13042 kN					1.0	**12.0**	1.0	**12.0**		Weights are In-House estimates
										Total Weight (MT):	**42.3**		**42.7**			

NOTES

Excluding:

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-3
Platform Weight Management Report
OTEC-2010-001

17 September 2010

Prepared for:

Naval Facilities Engineering Command
Naval Facilities Engineering Service Center (NFESC)
1100 23rd Avenue
Port Hueneme, CA 93043-4370
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Prepared by:

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Manassas, VA 20110

Distribution Statement A: Approved for public release; distribution is unlimited



Global Weight and Load Management Report

OTEC Pilot Power Plant
Semisubmersible Platform Design
kahe Point, Hawaii

HOE Project No. H09117

Rev	Date	Document Status	Originator	Checked	Approved
D	07/19/10	Update for Review	KS	NL	
C1	05/12/10	Hull Weight Update	KS	NL	
C	03/29/10	Load Cases Update	KS	NL	
B	02/04/10	Update for Review	KS	NL	
A	12/31/09	Preliminary template for comments	KS	NL	



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6 CENTER OF GRAVITY TRENDS 10
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8 PRINCIPAL DIMENSIONS SKETCH 13
9 DESIGN SUMMARY WEIGHT AND LOAD CASES 14

1 Introduction

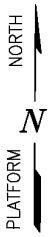
This document provides a management summary of the weight and load conditions of the 10 MW pilot plant semisubmersible platform design. This weight and load management report will be published on a regular basis to keep track of the weight and load conditions as the design of the platform develops.

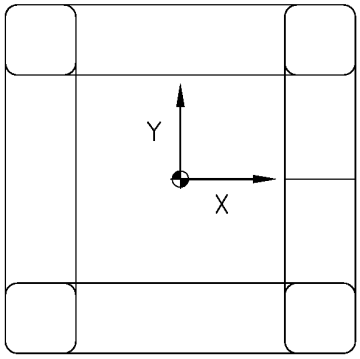
The purpose of this document is to present the weights, loads and center of gravity (C.G.) of the overall platform throughout the design phases, and eventually finalizing on a target weight budget. This weight and load inputs will be based on data and information provided by various contributing engineering work groups.

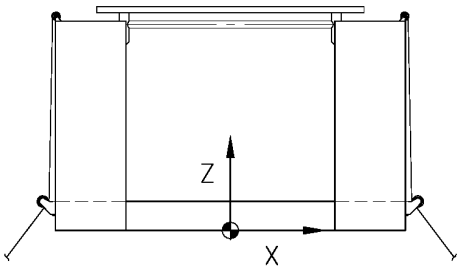
This revision (Rev-D) highlights the changes in weight, load and C.G. from the previous revision-C1. The objective of identifying the weight, load and C.G. budget is to highlight the design limits of these parameters to allow the overall global weight and load to stay within the agreed target budget throughout the different phases of the semisubmersible platform design.

Weight and load data are presented in units of metric tons (mt), C.G. data is presented in units of meter (m). The global coordinate system is defined as:

- (X,Y) origin = (0,0) at hull center
- Z = 0 at keel of hull
- Z positive upwards vertically
- Y positive to platform north
- X positive to platform east
- Roll, Pitch and Yaw are by the right hand rule.







2 Executive Summary

The following table (Table 2.1) provides the summary of weights/loads of the OTEC SEMI and changes from the previous revision, for the cases with and without the cold water pipe (CWP) manufacturing equipment.

Table 2.1: Summary of Weights for Operating/ Installation Conditions

	Full Production Condition (Load Case #201)	Fabrication Condition (Load Case#103)	Full Production Condition (Load Case #201)	Fabrication Condition, (Load Case#103)
Category	Current Weight (Rev C1)		Current Weight (Rev D)	
	Weight/Load	Weight/Load	Weight/Load	Weight/Load
	mt	mt	mt	mt
Deck Structure	2,164	2,164	2,164	2,164
Topside Equipments	983	914	1,698	1,570
Topside Bulk/Piping Wt.	197	197	340	340
CWP Fabrication Eqpts. (Incl. 7 days Staging Supply)	324	878	324	878
Hull fluid storage	0	0	0	0
CWP/El. line Vertical load	352	352	352	352
Payload Sub-Total	**4,020**	**4,505**	**4,878**	**5,305**
Hull Structure & Appurtenances	6,481	6,481	6,481	6,481
Mooring Vertical Loads	807	404	807	404
Non-Payload Sub-Total	**7,288**	**6,885**	**7,288**	**6,885**
Total W/O Remoras/Ballast	**11,308**	**11,390**	**12,166**	**12,189**
Remora - A	**8,061**	**-**	**8,042**	**-**
Remora - B	**8,061**	**-**	**8,042**	**-**
Entrained Water (Incl. Trim Ballas	8,067	7,984	7,246	7,186
Entrapped Water in Diffuser	261	261	261	261
Total (W/O Entrapped Water)	**35,497**	**19,374**	**35,496**	**19,375**
Total (W/ Entrapped Water)	**35,758**	**19,635**	**35,757**	**19,636**

Notes:

- Topside equipments include equipments and utilities associated with auxiliary systems and those required for OTEC Power generation systems.
- Cold water pipe (CWP) manufacturing equipments will be on the topside in the installation phase only.
- Fluid storage in hull is unknown at this stage of the design.
- Only 4 mooring lines will be installed during pipe manufacturing and pilot test phase. Four additional lines will be added later during full production condition.
- These weights include a margin which will be adjusted as the design information matures.

3 Load Cases

Table 3.1 shows the Load Cases considered for this preliminary design phase:-

Table 3.1: Summary of Load Cases

Case Number	Case Type	Remark
101	Lightship	
102	Wet Tow	Fully Integrated Hull & Topsides
103	Fabrication Condition	W/ CWP Manufacturing Eqpts, No Remoras
104	Pilot Testing Condition	One Remoras & One Power Unit Installed
201	Full Production Condition	Two Remoras & Both Power Unit Installed

4 Weight Trends

The weight trend data in this section is based on Load Case#201 (Full Production Condition). In the future revisions of this document, this section will highlight the changes in weights from the last revision/budget weight.

The Following Figures (4.1 to 4.3) show the weight data in the Topside and Hull category:

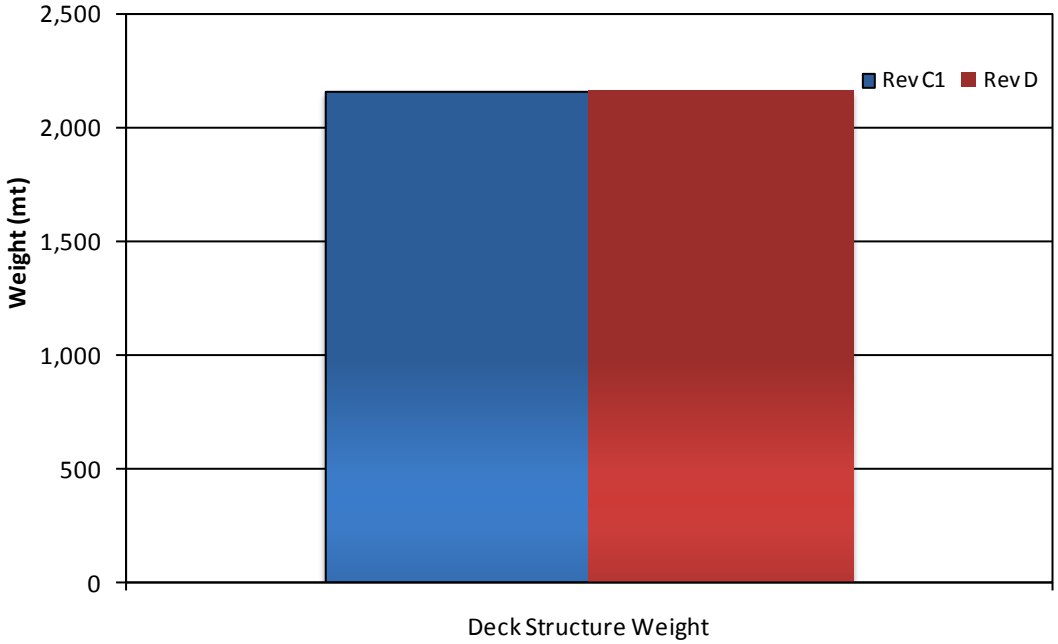


Figure 4.1: Topside Structure

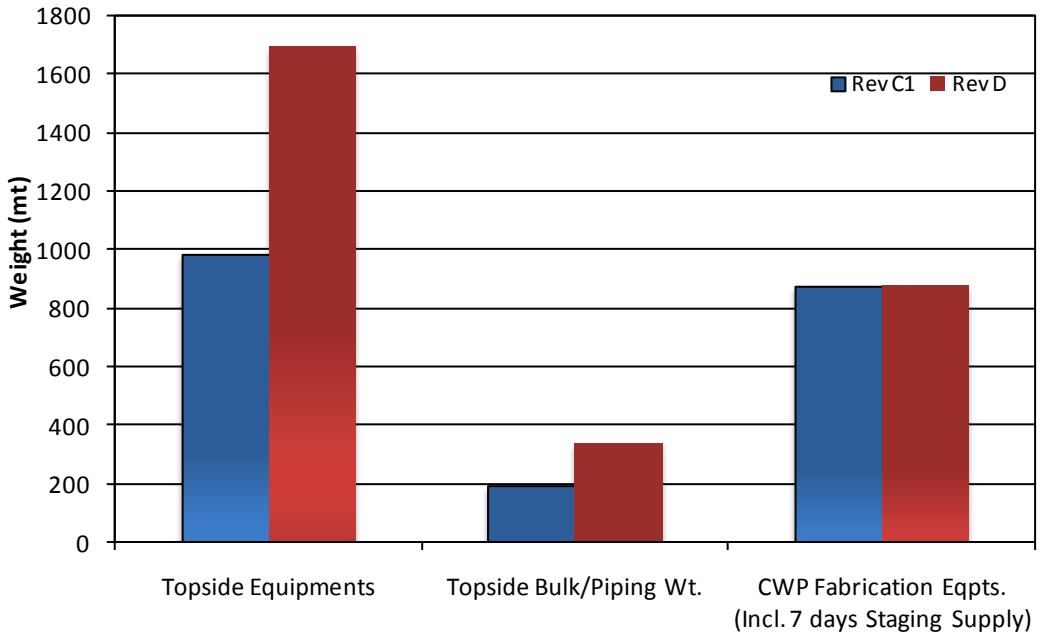


Figure 4.2: Topside Equipments

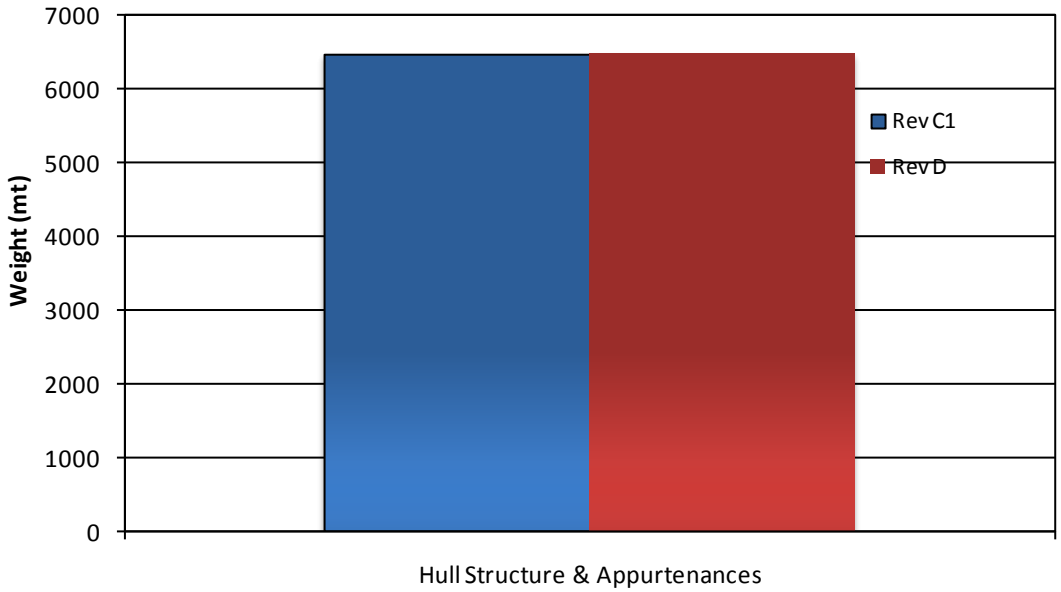


Figure 4.3: Hull Structure and appurtenances

5 Payload Tracking

The payload weight/load data used in this section is based on load case # 201 (Full Production Condition). Figure 6.1 shows payload breakdown and compares it from previous revision/budget.

Payload = Topside (Facilities + Deck) +Vertical Load (CWP + Electrical Line) + Hull Storage Fluids (if any?)

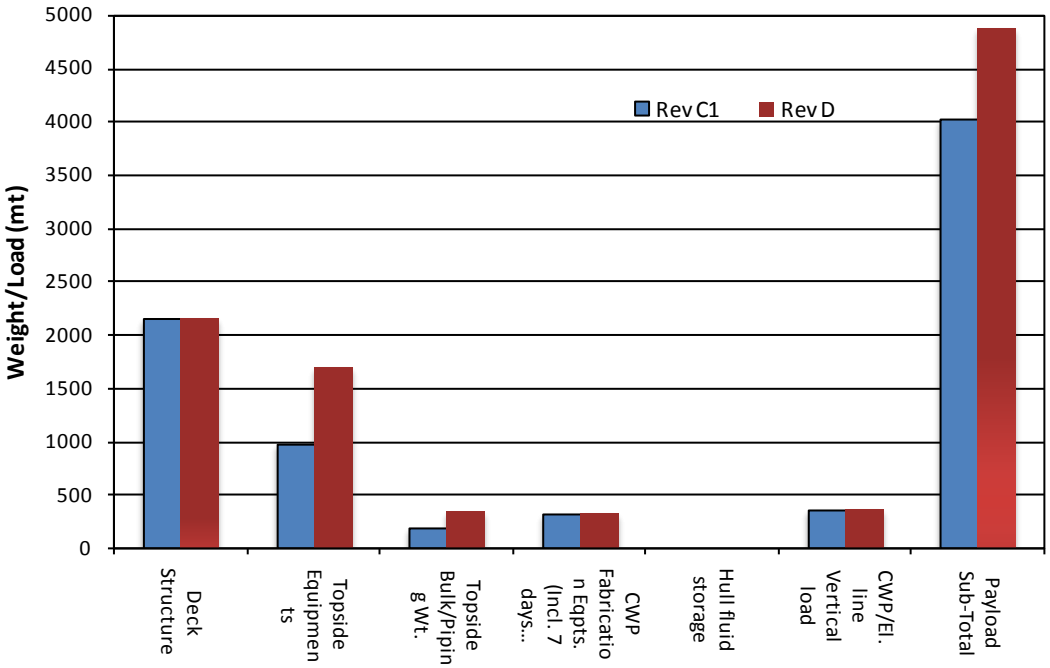


Figure 5.1: Payload Tracking

6 Center of Gravity Trends

The Center of Gravity (C.G.) data used in this section is based on Load case#102 (Wet Tow with fully integrated hull and topsides). Vertical C.G. of topside, hull and overall is shown in Figure 6.1 (will track changes in C.G. in future revisions). Overall Xcg and Ycg are shown in figure 6.2.

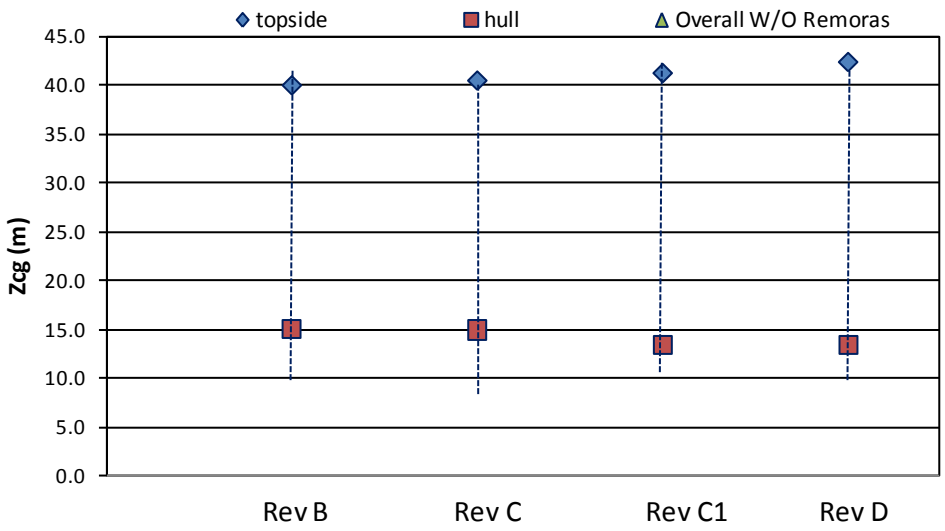


Figure 6.1: Vertical C.G. trend

- The overall Vcg is defined as after ballasting.
- Vertical C.G. is measured from the keel (See section 2 for coordinate system).
- Wet tow draft is not known at this stage of the project. Hence overall C.G. (being unknown) is not shown in the above figure.

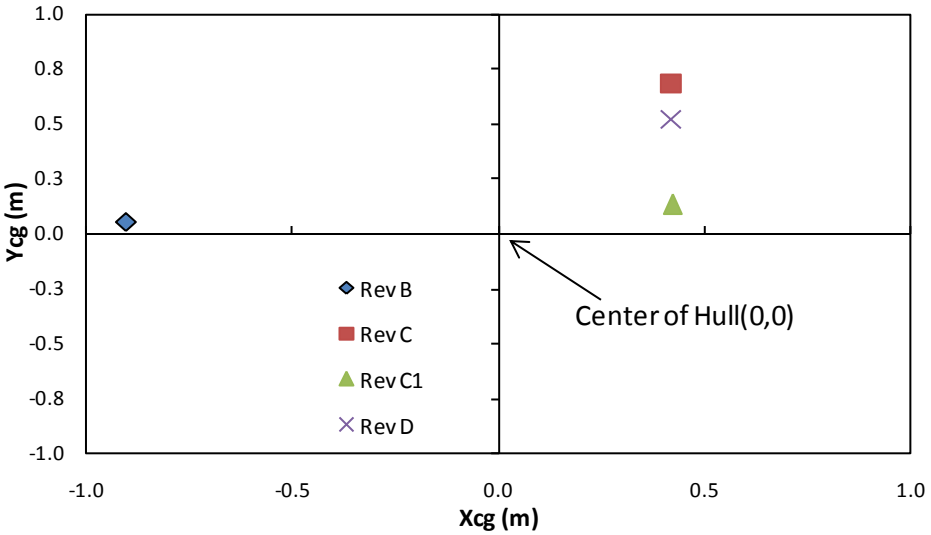


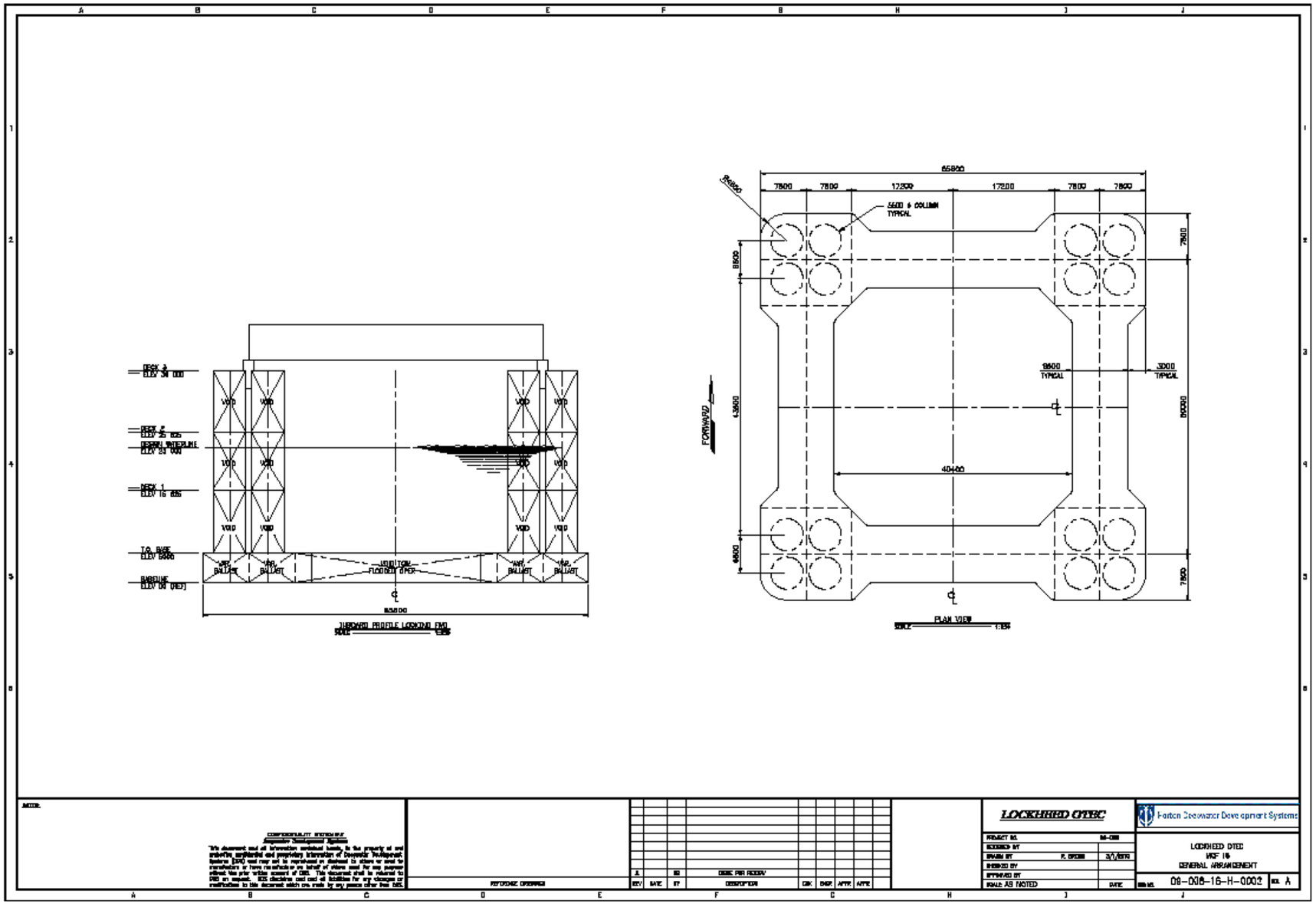
Figure 6.2: Overall Xcg & Ycg trend

- The overall horizontal C.G. is defined as after ballasting, but at this stage ballast in the wet tow condition is not known. Hence these numbers (Figure 6.2) are C.G. without any ballast.
- Origin of the coordinate system (0, 0) is center of the hull of Semi-submersible. (See section 2 for coordinate system).

7 Data Source

Discipline	Engineering Company	Revision
Facilities	HOE	As Per P Kitchen (Master Equipment List Rev C 07122010.xlsx)
Deck Structure, CWP Support	HOE	As per N.W. Lai (dated 02/01/2010)
CWP Manufacturing	Sound & Sea Technology	As per Weight Report (Wt and Load Estimate Summary by HOE for Topsides.xlsx)
Hull Structure & Outfittings	Horton Wison Deepwater, Inc.	Global Performance Report (Issued 10th April, 2010)
Hull Marine Utility Systems	HOE	As Per P Kitchen (Master Equipment List Rev C 07122010.xlsx)
Entrained Water	JHA	Report 2008-1-7A 10MW Platform Desciption.pdf
Mooring Vertical Load	JHA	Report 2008-1-7A 10MW Platform Desciption.pdf
CWP Vertical Load	Lockheed Martin	Report 2008-1-7A 10MW Platform Desciption.pdf
Remoras Weight	Makai & Associates	Report 2008-1-7A 10MW Platform Desciption.pdf
Ballast Water Weight	JHA	Report 2008-1-7A 10MW Platform Desciption.pdf

8 Principal Dimensions Sketch


65800
7800
7800
12200
17200
7800
7800
5600 ø COLUMN TYPICAL
8500
7800
9600 TYPICAL
3200 TYPICAL
43600
60000
FORWARD
40400
6500
7800
PLAN VIEW
DECK 3
ELEV 34' 000
DECK 2
ELEV 25' 625
DESIGN WATERLINE
ELEV 24' 000
DECK 1
ELEV 16' 625
T.O. KEEL
ELEV 5'000
BASELINE
ELEV 0' (REF)
VOID
VOID
VOID

9 Design Summary Weight and Load Cases

Table 9.1 to 9.4 shows the detailed weight, load and C.G. summary for all Load cases. Please note that numbers unknown at this stage of the project are blanked out from the load case summary.

Table 9.1: Weight Case#101; Lightship

Description		Weight (mts)	Load (mts)		XCG (EW) (m)	YCG (NS) (m)	ZCG (UP) (m)	Kxx (NS) (m)	Kyy (EW) (m)	Kzz (UP) (m)	FSC (mts-m)	Capacity (mts)
1 Topsides Equipments		2595	-	-	1.52	1.97	44.44					
2 Topsides Structure		2164	-	-	0.33	0.33	40.12					
3 Hull (Structure and Outfittings)		6481	-	-	0.00	0.00	13.49					
3 Hull Storage		0	-	-	0.00	0.00	10.62					
4 Entrapped Water in Diffuser		0	-	-	0.00	0.00	5.00					
5 Remora - A		0	-	-	-25.00	0.00	14.30					
6 Remora - B		0	-	-	25.00	0.00	14.30					
Weight Sub-total		11,240			0.42	0.52	25.76					
5 Mooring Loads		-	0		0.00	0.00	0.00	-	-	-	-	-
6 Cold Water Pipe Loads		-	0		0.00	0.00	0.00	-	-	-	-	-
Load Sub-total			0		0.00	0.00	0.00					
Weight & Force Sub-Total		11,240										
Ballast Tanks:	Type		Load (%)	Sounding (m)				L	B	H		
North East Tanks												
NE Tank	Variable Ballast Tank	0	0.0%	0.00	20.30	20.30	0.00	10.0	10.0	5.0	0	501
South East Tanks												
SE Tank	Variable Ballast Tank	0	0.0%	0.00	20.30	-20.30	0.00	10.0	10.0	5.0	0	501
South West Tanks												
SW Tank	Variable Ballast Tank	0	0.0%	0.00	-20.30	-20.30	0.00	10.0	10.0	5.0	0	501
North West Tanks												
NW Tank	Variable Ballast Tank	0	0.0%	0.00	-20.30	20.30	0.00	10.0	10.0	5.0	0	501
Permanently Flooded Tanks												
13S1		0	0.0%	0.00	11.30	25.00	0.00	11.3	11.3	5.0	0	646
20S1		0	0.0%	0.00	25.00	11.30	0.00	11.3	11.3	5.0	0	646
40S1		0	0.0%	0.00	25.00	-11.30	0.00	11.3	11.3	5.0	0	646
53S1		0	0.0%	0.00	11.30	-25.00	0.00	11.3	11.3	5.0	0	646
53P1		0	0.0%	0.00	-11.30	-25.00	0.00	11.3	11.3	5.0	0	646
40P1		0	0.0%	0.00	-25.00	-11.30	0.00	11.3	11.3	5.0	0	646
20P1		0	0.0%	0.00	-25.00	11.30	0.00	11.3	11.3	5.0	0	646
13P1		0	0.0%	0.00	-11.30	25.00	0.00	11.3	11.3	5.0	0	646
30S1		0	0.0%	0.00	25.00	0.00	0.00	9.6	9.5	5.0	0	456
50C1		0	0.0%	0.00	0.00	-25.00	0.00	9.5	9.6	5.0	0	456
30P1		0	0.0%	0.00	-25.00	0.00	0.00	9.6	9.5	5.0	0	456
10C1		0	0.0%	0.00	0.00	25.00	0.00	9.5	9.6	5.0	0	456
	Total Variable Ballast	0			20.30	20.30	0.00	32.6	32.7	28.3	000E+0	9E+3
	(Trim+Reserve) ballast	0			20.30	20.30	0.00					
	Residul ballast	0			0.00	0.00	0.00					
	Total Mass	11,240			0.42	0.52	25.76					

Displacement	=	11240	mts	FS_corr	=		m		KMT	=		m
Total liquid	=	0	mts	KB	=		m		KML	=		m
Draft@gauge	=		m	KG	=		m		GMT (NS)	=		m
				KG_corr	=		m		GML (EW)	=		m
xcg: load+wt	(including	=	0.42 m	Heel (NS)	=		degs		GMT_corr(NS	=		m
ycg: load+wt	moorings &	=	0.52 m	Trim (EW	=		degs		GML_corr(EW	=		m
zcg: load+wt	cwp)	=	25.76 m	LCF	=		m		(NS)	=		m
				LCB	=		m		Kyy-Pitch (EW)	=		m
Total Mass Incl. CWP		=	11,240 mts	GMT (NS)	=		m	(w/	Kzz-Yaw (UP)	=		m
xcg: load+wt	(excluding	=	0.42 m	GML (EW	=		m	mooring	(XCG toward platform east - positive)			
ycg: load+wt	moorings &	=	0.52 m	GMT_corr	=		m	& cwp)	(YCG toward platform north - positive)			
zcg: load+wt	incl. cwp)	=	25.76 m	GML_corr	=		m		(ZCG up from base line)			

Table 9.2: Weight Case#102; Wet Tow with fully integrated hull, topsides

Description	Weight (mts)	Load (mts)		XCG (EW) (m)	YCG (NS) (m)	ZCG (UP) (m)	Kxx (NS) (m)	Kyy (EW) (m)	Kzz (UP) (m)	FSC (mts-m)	Capacity (mts)
1 Topsides Equipments	2595	-	-	1.52	1.97	44.44					
2 Topsides Structure	2164	-	-	0.33	0.33	40.12					
3 Hull (Structure and Outfittings)	6481	-	-	0.00	0.00	13.49					
3 Hull Storage	0	-	-	0.00	0.00	10.62					
4 Entrapped Water in Diffuser	0	-	-	0.00	0.00	5.00					
5 Remora - A	0	-	-	-25.00	0.00	14.30					
6 Remora - B	0	-	-	25.00	0.00	14.30					
Weight Sub-total	11,240			0.42	0.52	25.76					
5 Mooring Loads	-	0		0.00	0.00	0.00	-	-	-	-	-
6 Cold Water Pipe Loads	-	0		0.00	0.00	0.00	-	-	-	-	-
Load Sub-total		0		0.00	0.00	0.00					
Weight & Force Sub-Total	11,240										
Ballast Tanks: Type		Load (%)	Sounding (m)				L	B	H		
North East Tanks											
NE Tank Variable Ballast Tank	0	0.0%	0.00	20.30	20.30	0.00	10.0	10.0	5.0	0	501
South East Tanks											
SE Tank Variable Ballast Tank	0	0.0%	0.00	20.30	-20.30	0.00	10.0	10.0	5.0	0	501
South West Tanks											
SW Tank Variable Ballast Tank	0	0.0%	0.00	-20.30	-20.30	0.00	10.0	10.0	5.0	0	501
North West Tanks											
NW Tank Variable Ballast Tank	0	0.0%	0.00	-20.30	20.30	0.00	10.0	10.0	5.0	0	501
Permanently Flooded Tanks											
13S1	0	0.0%	0.00	11.30	25.00	0.00	11.3	11.3	5.0	0	646
20S1	0	0.0%	0.00	25.00	11.30	0.00	11.3	11.3	5.0	0	646
40S1	0	0.0%	0.00	25.00	-11.30	0.00	11.3	11.3	5.0	0	646
53S1	0	0.0%	0.00	11.30	-25.00	0.00	11.3	11.3	5.0	0	646
53P1	0	0.0%	0.00	-11.30	-25.00	0.00	11.3	11.3	5.0	0	646
40P1	0	0.0%	0.00	-25.00	-11.30	0.00	11.3	11.3	5.0	0	646
20P1	0	0.0%	0.00	-25.00	11.30	0.00	11.3	11.3	5.0	0	646
13P1	0	0.0%	0.00	-11.30	25.00	0.00	11.3	11.3	5.0	0	646
30S1	0	0.0%	0.00	25.00	0.00	0.00	9.6	9.5	5.0	0	456
50C1	0	0.0%	0.00	0.00	-25.00	0.00	9.5	9.6	5.0	0	456
30P1	0	0.0%	0.00	-25.00	0.00	0.00	9.6	9.5	5.0	0	456
10C1	0	0.0%	0.00	0.00	25.00	0.00	9.5	9.6	5.0	0	456
Total Variable Ballast	0			20.30	20.30	0.00	32.6	32.7	28.3	000E+0	9E+3
(Trim+Reserve) ballast	0			20.30	20.30	0.00					
Residul ballast	0			0.00	0.00	0.00					
Total Mass	11,240			0.42	0.52	25.76					

Displacement	=	11240	mts	FS_corr	=	m		KMT	=	m
Total liquid	=	0	mts	KB	=	m		KML	=	m
Draft@gauge	=		m	KG	=	m		GMT (NS)	=	m
				KG_corr	=	m		GML (EW)	=	m
xcg: load+wt	(including	=	0.42 m	Heel (NS)	=	degs		GMT_corr(NS	=	m
ycg: load+wt	moorings &	=	0.52 m	Trim (EW	=	degs		GML_corr(EW	=	m
zcg: load+wt	cwp)	=	25.76 m	LCF	=	m		(NS)	=	m
				LCB	=	m		Kyy-Pitch (EW)	=	m
Total Mass Incl. CWP		=	11,240 mts	GMT (NS)	=	m	(w/	Kzz-Yaw (UP)	=	m
xcg: load+wt	(excluding	=	0.42 m	GML (EW	=	m	mooring	(XCG toward platform east - positive)		
ycg: load+wt	moorings &	=	0.52 m	GMT_corr	=	m	& cwp)	(YCG toward platform north - positive)		
zcg: load+wt	incl. cwp)	=	25.76 m	GML_corr	=	m		(ZCG up from base line)		

Table 9.3: Weight Case#103; Fabrication Condition (Incl. Whole Length CWP, No Remoras)

Description	Weight (mts)	Load (mts)		XCG (EW) (m)	YCG (NS) (m)	ZCG (UP) (m)	Kxx (NS) (m)	Kyy (EW) (m)	Kzz (UP) (m)	FSC (mts-m)	Capacity (mts)
1 Topsides Equipments	2788	-	-	0.68	1.67	45.79					
2 Topsides Structure	2164	-	-	0.33	0.33	40.12					
3 Hull (Structure and Outfittings)	6481	-	-	0.00	0.00	13.49					
3 Hull Storage	0	-	-	0.00	0.00	10.62					
4 Entrapped Water in Diffuser	261	-	-	0.00	0.00	5.00					
5 Remora - A	0	-	-	-25.00	0.00	14.30					
6 Remora - B	0	-	-	25.00	0.00	14.30					
Weight Sub-total	11,694			0.22	0.46	25.93					
5 Mooring Loads	-	403		0.00	0.00	3.00	-	-	-	-	-
6 Cold Water Pipe Loads	-	352		0.00	0.00	1.50	-	-	-	-	-
Load Sub-total		755		0.00	0.00	2.30					
Weight & Force Sub-Total	12,449										
Ballast Tanks: Type		Load (%)	Sounding (m)				L	B	H		
North East Tanks											
NE Tank Variable Ballast Tank	0	0.0%	0.00	20.30	20.30	0.00	10.0	10.0	5.0	0	501
South East Tanks											
SE Tank Variable Ballast Tank	25	5.0%	0.25	20.30	-20.30	0.13	10.0	10.0	5.0	101	501
South West Tanks											
SW Tank Variable Ballast Tank	165	33.0%	1.65	-20.30	-20.30	0.83	10.0	10.0	5.0	71	501
North West Tanks											
NW Tank Variable Ballast Tank	0	0.0%	0.00	-20.30	20.30	0.00	10.0	10.0	5.0	0	501
Permanently Flooded Tanks											
13S1	646	100.0%	5.00	11.30	25.00	2.50	11.3	11.3	5.0	0	646
20S1	646	100.0%	5.00	25.00	11.30	2.50	11.3	11.3	5.0	0	646
40S1	646	100.0%	5.00	25.00	-11.30	2.50	11.3	11.3	5.0	0	646
53S1	646	100.0%	5.00	11.30	-25.00	2.50	11.3	11.3	5.0	0	646
53P1	646	100.0%	5.00	-11.30	-25.00	2.50	11.3	11.3	5.0	0	646
40P1	646	100.0%	5.00	-25.00	-11.30	2.50	11.3	11.3	5.0	0	646
20P1	646	100.0%	5.00	-25.00	11.30	2.50	11.3	11.3	5.0	0	646
13P1	646	100.0%	5.00	-11.30	25.00	2.50	11.3	11.3	5.0	0	646
30S1	456	100.0%	5.00	25.00	0.00	2.50	9.6	9.5	5.0	0	456
50C1	456	100.0%	5.00	0.00	-25.00	2.50	9.5	9.6	5.0	0	456
30P1	456	100.0%	5.00	-25.00	0.00	2.50	9.6	9.5	5.0	0	456
10C1	456	100.0%	5.00	0.00	25.00	2.50	9.5	9.6	5.0	0	456
Total Variable Ballast	7,186			-0.40	-0.54	2.45	24.2	24.2	27.2	172E+0	9E+3
(Trim+Reserve) ballast	7,186			-0.40	-0.54	2.45					
Residul ballast	0			0.00	0.00	0.00					
Total Mass	18,880			-0.01	0.08	16.99					

Displacement	=	19635	mts	FS_corr	=	0.01	m		KMT	=	19.4 m
Total liquid	=	7186	mts	KB	=	6.70	m		KML	=	19.4 m
Draft@gauge	=	23.00	m	KG	=	16.99	m		GMT (NS)	=	2.41 m
				KG_corr	=	17.00	m		GML (EW)	=	2.41 m
xcg: load+wt	(including	=	-0.01 m	Heel (NS)	=		degs		GMT_corr(NS	=	2.40 m
ycg: load+wt	moorings &	=	0.08 m	Trim (EW	=		degs		GML_corr(EW	=	2.40 m
zcg: load+wt	cwp)	=	16.43 m	LCF	=	0.0	m		(NS)	=	26.6 m
				LCB	=	0.0	m		Kyy-Pitch (EW)	=	26.6 m
Total Mass Incl. CWP		=	19,232 mts	GMT (NS)	=	2.97	m	(w/	Kzz-Yaw (UP)	=	28.6 m
xcg: load+wt	(excluding	=	-0.01 m	GML (EW	=	2.97	m	mooring	(XCG toward platform east - positive)		
ycg: load+wt	moorings &	=	0.08 m	GMT_corr	=	2.97	m	& cwp)	(YCG toward platform north - positive)		
zcg: load+wt	incl. cwp)	=	16.71 m	GML_corr	=	2.97	m		(ZCG up from base line)		

Table 9.4: Weight Case#104; Pilot Testing Condition (One Remora and One Power Unit Installed)

Description		Weight (mts)	Load (mts)		XCG (EW) (m)	YCG (NS) (m)	ZCG (UP) (m)	Kxx (NS) (m)	Kyy (EW) (m)	Kzz (UP) (m)	FSC (mts-m)	Capacity (mts)
1 Topsides Equipments		2234	-	-	2.62	2.48	43.90					
2 Topsides Structure		2164	-	-	0.33	0.33	40.12					
3 Hull (Structure and Outfittings)		6481	-	-	0.00	0.00	13.49					
3 Hull Storage		0	-	-	0.00	0.00	10.62					
4 Entrapped Water in Diffuser		261	-	-	0.00	0.00	5.00					
5 Remora - A		8042	-	-	-38.64	0.00	-14.40					
6 Remora - B		0	-	-	38.64	0.00	-14.40					
Weight Sub-total		19,182			-15.86	0.33	8.23					
5 Mooring Loads		-	403		0.00	0.00	3.00	-	-	-	-	-
6 Cold Water Pipe Loads		-	352		0.00	0.00	1.50	-	-	-	-	-
Load Sub-total			755		0.00	0.00	2.30					
Weight & Force Sub-Total		19,937										
Ballast Tanks:	Type		Load (%)	Sounding (m)				L	B	H		
North East Tanks												
NE Tank	Variable Ballast Tank	186	37.2%	1.86	20.30	20.30	0.93	10.0	10.0	5.0	67	501
South East Tanks												
SE Tank	Variable Ballast Tank	186	37.2%	1.86	20.30	-20.30	0.93	10.0	10.0	5.0	67	501
South West Tanks												
SW Tank	Variable Ballast Tank	186	37.2%	1.86	-20.30	-20.30	0.93	10.0	10.0	5.0	67	501
North West Tanks												
NW Tank	Variable Ballast Tank	186	37.2%	1.86	-20.30	20.30	0.93	10.0	10.0	5.0	67	501
Permanently Flooded Tanks												
13S1		646	100.0%	5.00	11.30	25.00	2.50	11.3	11.3	5.0	0	646
20S1		646	100.0%	5.00	25.00	11.30	2.50	11.3	11.3	5.0	0	646
40S1		646	100.0%	5.00	25.00	-11.30	2.50	11.3	11.3	5.0	0	646
53S1		646	100.0%	5.00	11.30	-25.00	2.50	11.3	11.3	5.0	0	646
53P1		646	100.0%	5.00	-11.30	-25.00	2.50	11.3	11.3	5.0	0	646
40P1		646	100.0%	5.00	-25.00	-11.30	2.50	11.3	11.3	5.0	0	646
20P1		646	100.0%	5.00	-25.00	11.30	2.50	11.3	11.3	5.0	0	646
13P1		646	100.0%	5.00	-11.30	25.00	2.50	11.3	11.3	5.0	0	646
30S1		456	100.0%	5.00	25.00	0.00	2.50	9.6	9.5	5.0	0	456
50C1		456	100.0%	5.00	0.00	-25.00	2.50	9.5	9.6	5.0	0	456
30P1		456	100.0%	5.00	-25.00	0.00	2.50	9.6	9.5	5.0	0	456
10C1		456	100.0%	5.00	0.00	25.00	2.50	9.5	9.6	5.0	0	456
	Total Variable Ballast	7,741			0.00	0.00	2.35	19.9	22.8	29.6	267E+0	9E+3
	(Trim+Reserve) ballast	7,741			0.00	0.00	2.35					
	Residul ballast	0			0.00	0.00	0.00					
	Total Mass	26,923			-11.30	0.23	6.54					

Displacement	=	27678	mts	FS_corr	=	0.01	m	KMT	=	28.4 m
Total liquid	=	7741	mts	KB	=	4.90	m	KML	=	15.0 m
Draft@gauge	=	23.00	m	KG	=	6.54	m	GMT (NS)	=	21.86 m
				KG_corr	=	6.54	m	GML (EW)	=	8.46 m
xcg: load+wt	(including	-10.99	m	Heel (NS)	=		degs	GMT_corr(NS	=	21.86 m
ycg: load+wt	moorings &	0.23	m	Trim (EW	=		degs	GML_corr(EW	=	8.46 m
zcg: load+wt	cwp) =	6.42	m	LCF	=		m	(NS)	=	31.2 m
				LCB	=		m	Kyy-Pitch (EW)	=	36.1 m
Total Mass Incl. CWP	=	27,275	mts	GMT (NS)	=	21.98	m	Kzz-Yaw (UP)	=	31.1 m
xcg: load+wt	(excluding	-11.15	m	GML (EW	=	8.58	m	(w/ mooring & cwp)	(XCG toward platform east - positive)	
ycg: load+wt	moorings &	0.23	m	GMT_corr	=	21.97	m		(YCG toward platform north - positive)	
zcg: load+wt	incl. cwp) =	6.47	m	GML_corr	=	8.57	m		(ZCG up from base line)	

Table 9.5: Weight Case#201; Full Production Condition, Two Remoras and Both Power Unit Installed

Description	Weight (mts)	Load (mts)		XCG (EW) (m)	YCG (NS) (m)	ZCG (UP) (m)	Kxx (NS) (m)	Kyy (EW) (m)	Kzz (UP) (m)	FSC (mts-m)	Capacity (mts)
1 Topsides Equipments	2362	-	-	3.70	3.14	43.97					
2 Topsides Structure	2164	-	-	0.33	0.33	40.12					
3 Hull (Structure and Outfittings)	6481	-	-	0.00	0.00	13.49					
3 Hull Storage	0	-	-	0.00	0.00	10.62					
4 Entrapped Water in Diffuser	261	-	-	0.00	0.00	5.00					
5 Remora - A	8042	-	-	-38.64	0.00	-14.40					
6 Remora - B	8042	-	-	38.64	0.00	-14.40					
Weight Sub-total	27,351			0.35	0.30	1.75					
5 Mooring Loads	-	807		0.00	0.00	3.00	-	-	-	-	-
6 Cold Water Pipe Loads	-	352		0.00	0.00	1.50	-	-	-	-	-
Load Sub-total		1,159		0.00	0.00	2.54					
Weight & Force Sub-Total	28,510										
Ballast Tanks:	Type		Load (%)	Sounding (m)			L	B	H		
North East Tanks											
NE Tank	Variable Ballast Tank	0	0.0%	0.00	20.30	20.30	0.00	10.0	10.0	5.0	0	501
South East Tanks											
SE Tank	Variable Ballast Tank	0	0.0%	0.00	20.30	-20.30	0.00	10.0	10.0	5.0	0	501
South West Tanks											
SW Tank	Variable Ballast Tank	218	43.5%	2.17	-20.30	-20.30	1.09	10.0	10.0	5.0	60	501
North West Tanks											
NW Tank	Variable Ballast Tank	0	0.0%	0.00	-20.30	20.30	0.00	10.0	10.0	5.0	0	501
Permanently Flooded Tanks											
13S1		646	100.0%	5.00	11.30	25.00	2.50	11.3	11.3	5.0	0	646
20S1		646	100.0%	5.00	25.00	11.30	2.50	11.3	11.3	5.0	0	646
40S1		646	100.0%	5.00	25.00	-11.30	2.50	11.3	11.3	5.0	0	646
53S1		646	100.0%	5.00	11.30	-25.00	2.50	11.3	11.3	5.0	0	646
53P1		646	100.0%	5.00	-11.30	-25.00	2.50	11.3	11.3	5.0	0	646
40P1		646	100.0%	5.00	-25.00	-11.30	2.50	11.3	11.3	5.0	0	646
20P1		646	100.0%	5.00	-25.00	11.30	2.50	11.3	11.3	5.0	0	646
13P1		646	100.0%	5.00	-11.30	25.00	2.50	11.3	11.3	5.0	0	646
30S1		456	100.0%	5.00	25.00	0.00	2.50	9.6	9.5	5.0	0	456
50C1		456	100.0%	5.00	0.00	-25.00	2.50	9.5	9.6	5.0	0	456
30P1		456	100.0%	5.00	-25.00	0.00	2.50	9.6	9.5	5.0	0	456
10C1		456	100.0%	5.00	0.00	25.00	2.50	9.5	9.6	5.0	0	456
	Total Variable Ballast	7,213			-0.61	-0.61	2.46	19.3	19.3	27.3	60E+0	9E+3
	(Trim+Reserve) ballast	7,213			-0.61	-0.61	2.46					
	Residul ballast	0			0.00	0.00	0.00					
	Total Mass	34,564			0.15	0.11	1.90					

Displacement	=	35723	mts	FS_corr	=	0.001	m	KMT	= 34.2 m
Total liquid	=	7213	mts	KB	=	3.70	m	KML	= 12.1 m
Draft@gauge	=	23.00	m	KG	=	1.90	m	GMT (NS)	= 32.30 m
				KG_corr	=	1.90	m	GML (EW)	= 10.20 m
xcg: load+wt	(including	= 0.141	m	Heel (NS)	=		degs	GMT_corr(NS	= 32.30 m
ycg: load+wt	moorings &	= 0.104	m	Trim (EW	=		degs	GML_corr(EW	= 10.20 m
zcg: load+wt	cwp)	= 1.92	m	LCF	=		m	(NS)	= 33.3 m
				LCB	=		m	Kyy-Pitch (EW)	= 43.6 m
Total Mass Incl. CWP		= 34,916	mts	GMT (NS)	=	32.28	m	Kzz-Yaw (UP)	= 36.3 m
xcg: load+wt	(excluding	= 0.14	m	GML (EW	=	10.18	m	(w/ mooring & cwp)	(XCG toward platform east - positive)
ycg: load+wt	moorings &	= 0.11	m	GMT_corr	=	32.28	m		(YCG toward platform north - positive)
zcg: load+wt	incl. cwp)	= 1.89	m	GML_corr	=	10.18	m		(ZCG up from base line)

5 MW Pilot Test Phase, OTEC Platform Topsides Weight Summary - Pilot Testing Condition

TOPSIDES EQUIPMENT LIST	No of units	unit wt (mt)	Net Weight (mt)	Contingency %	Contingency (mt)	TOTAL WEIGHT (mt)	CENTER OF GRAVITY X m	Y m	Z (from MWL) m	Z (from keel) m
CWP Fabrication										
CWP Fabrication Equipment										
CWP env. Enclosure Steel Weight	-	-	0.0	15.0%	0.0	0.0	-10.7	-2.3	40.0	63.0
Enclosure Panels	-	-	0.0	15.0%	0.0	0.0	-10.7	-2.3	40.0	63.0
Live load people	20	0.091	0.0	0.0%	0.0	0.0	-10.7	-2.3	43.1	66.1
HVAC Equipment	2	1.451	0.0	15.0%	0.0	0.0	9.0	-2.5	22.0	45.0
Hydraulic HPU	-	-	0.0	15.0%	0.0	0.0	-10.7	-2.3	22.0	45.0
Total (CWP Fabrication Eqpt)			**0.0**	**#DIV/0!**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
CWP Fabrication Bulk Material (7 days staging supply)										
Face Sheet Rolls (Inner Rolls in 1 containers)	0	0.816	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Face Sheet Rolls (Outer Rolls in 1 containers)	0	0.816	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Pultruded Planks (5 containers)	0	0.142	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Container Weight	0	4.000	0.0	5.0%	0.0	0.0	-10.7	-2.3	22.0	45.0
Resin (Tote Tanks)	0	2.100	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Catalyst	0	0.210	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Promoter	0	0.224	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Accelerator	0	0.168	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
RDM rolls	0	0.425	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Total (CWP Bulk Material)			**0.0**	**#DIV/0!**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
CWP Fabrication Apparatus										
CWP Fabrication Tower Apparatus			153.0	25.0%	38.3	191.3	0.0	0.0	40.0	63.0
Top Gripper structure	-	rem	20.0	25.0%	5.0	25.0	0.0	0.0	12.5	35.5
Bottom Gripper	-	rem	20.0	25.0%	5.0	25.0	0.0	0.0	4.5	27.5
Top Gripper pads	-	remove	0.0	30.0%	0.0	0.0	0.0	0.0	12.5	35.5
Bottom Gripper pads		remove	0.0	30.0%	0.0	0.0	0.0	0.0	4.5	27.5
Heave Compensator	-	rem	4.0	30.0%	1.2	5.2	0.0	0.0	17.0	40.0
Hardware & Accessories	-	remove	0.0	30.0%	0.0	0.0	0.0	0.0	17.0	40.0
Gimbal Structure	-	rem	60.0	30.0%	18.0	78.0	0.0	0.0	-3.0	20.0
Total (CWP Apparatus)			**153.0**	**25.0%**	**38.3**	**324.5**	**0.0**	**0.0**	**24.4**	**47.4**
Total CWP Fabrication eqpts.			**153.0**	**25.0%**	**38.3**	**324.5**	**0.0**	**0.0**	**24.4**	**47.4**
Topsides Utilities & Power Equipment										
44 - OILY WATER										
Topsides Oily Water Sump Tank	1	4.2	4.2	15.0%	0.6	4.9	0.7	14.6	16.0	39.0
Oily Water Separator	1	2.2	2.2	15.0%	0.3	2.5	2.9	15.1	16.0	39.0
50 - SEAWATER										
Seawater Lift Pump	1	5.5	5.5	15.0%	0.8	6.3	33.1	-22.7	12.5	35.5
Seawater Lift Pump	1	5.5	5.5	15.0%	0.8	6.3	33.1	-23.5	12.5	35.5
Sanitary Water Pressure Set	1	2.3	2.3	15.0%	0.3	2.6	0.0	0.0	22.0	45.0

5 MW Pilot Test Phase, OTEC Platform Topsides Weight Summary - Pilot Testing Condition

TOPSIDES EQUIPMENT LIST	No of units	unit wt (mt)	Net Weight (mt)	Contingency %	Contingency (mt)	TOTAL WEIGHT (mt)	CENTER OF GRAVITY X m	Y m	Z (from MWL) m	Z (from keel) m
53 - FRESH WATER										
Fresh Water Maker	1	1.98	2.0	15.0%	0.3	2.3	15.9	19.4	16.0	39.0
Potable Water Pressure Set	1	2.3	2.3	15.0%	0.3	2.6	15.9	22.4	16.0	39.0
Fresh Water Storage Tank	1	19.9	19.9	15.0%	3.0	22.9	15.8	14.5	16.0	39.0
Fresh Water Storage Tank	1	19.9	19.9	15.0%	3.0	22.9	19.9	14.5	16.0	39.0
Washdown Water Skid	1	1.9	1.9	15.0%	0.3	2.2	7.3	22.4	16.0	39.0
Washdown Water Pmp Motor	1	1.9	1.9	15.0%	0.3	2.2	7.3	22.4	16.0	39.0
62 - DIESEL										
Diesel Transfer Skid	1	3.0	3.0	10.0%	0.3	3.3	7.1	-19.8	22.0	45.0
Diesel Storage Tank	1	43.0	43.0	10.0%	4.3	47.3	10.2	-24.9	22.0	45.0
Diesel Storage Tank	1	43.0	43.0	10.0%	4.3	47.3	10.2	-24.9	22.0	45.0
63 - COMPRESSED AIR										
Air Compressor Skid	1	5.0	5.0	15.0%	0.8	5.8	6.5	14.5	16.0	39.0
Air Compressor	1		0.0	15.0%	0.0	0.0	6.5	14.5	16.0	39.0
Air Cooler (Radiator Type) Fan Motor	1		0.0	15.0%	0.0	0.0	6.5	14.5	16.0	39.0
Air Compressor (Standby)	1		0.0	15.0%	0.0	0.0	6.5	14.5	16.0	39.0
Air Cooler (Radiator Type) Fan Motor	1		0.0	15.0%	0.0	0.0	6.5	14.5	16.0	39.0
Instrument Air Dryer	1		0.0	15.0%	0.0	0.0	3.1	20.8	16.0	39.0
Instrument Air Receiver	1	3.2	3.2	15.0%	0.5	3.7	3.1	20.8	16.0	39.0
Utility Air Receiver	1	4.0	4.0	15.0%	0.6	4.6	0.8	21.1	16.0	39.0
Black Start Air Compressor Skid	1	2.7	2.7	15.0%	0.4	3.2	7.0	19.5	16.0	39.0
66 - SEWAGE TREATMENT										
Sewage Treatment Plant	1	1.6	1.6	15.0%	0.2	1.8	22.5	18.1	16.0	39.0
Pump 5020A Motor	1		0.0	15.0%	0.0	0.0	22.5	18.1	16.0	39.0
Pump 5020B Motor (Standby Pump Motor)	1		0.0	15.0%	0.0	0.0	22.5	18.1	16.0	39.0
Bolwer 5020C Motor	1		0.0	15.0%	0.0	0.0	22.5	18.1	16.0	39.0
71- FIREWATER										
Firewater Pump Package	1	1.1	1.1	15.0%	0.2	1.3	0.0	0.0	12.5	35.5
Firewater Pump	1		0.0	15.0%	0.0	0.0	0.0	0.0	12.5	35.5
Firewater Pump Motor			0.0	15.0%	0.0	0.0	0.0	0.0	12.5	35.5
Firewater Pump Package (Standby)	1	1.1	1.1	15.0%	0.2	1.3	0.0	0.0	12.5	35.5
Firewater Pump	1		0.0	15.0%	0.0	0.0	0.0	0.0	12.5	35.5
Firewater Pump Motor			0.0	15.0%	0.0	0.0	0.0	0.0	12.5	35.5
73 - MATERIAL HANDLING										
Pedestal Crane	1	90.0	90.0	15.0%	13.5	103.5	-10.2	25.0	27.0	50.0
Hydraulic Pump Motor										
Pedestal Crane (Lighting, A/c and Misc. Loads)										
Pedestal Crane	1	90.0	90.0	15.0%	13.5	103.5	10.2	-25.0	27.0	50.0
Hydraulic Pump Motor										
Pedestal Crane (Lighting, A/c and Misc. Loads)										

5 MW Pilot Test Phase, OTEC Platform Topsides Weight Summary - Pilot Testing Condition

TOPSIDES EQUIPMENT LIST	No of units	unit wt (mt)	Net Weight (mt)	Contingency %	Contingency (mt)	TOTAL WEIGHT (mt)	CENTER OF GRAVITY X m	Y m	Z (from MWL) m	Z (from keel) m
76 - SAFETY EQUIPMENT										
Survival Craft	2	4.5	9.0	15.0%	1.4	10.4	29.6	11.6	21.0	44.0
Winch on the Davit has a 25 kW 2-Speed Motor			0.0	15.0%	0.0	0.0	0.0	0.0	21.0	44.0
Survival Craft	2	4.5	9.0	15.0%	1.4	10.4	-29.6	11.6	21.0	44.0
Winch on the Davit has a 25 kW 2-Speed Motor			0.0	15.0%	0.0	0.0	0.0	0.0	21.0	44.0
Rescue Craft	1	2.2	2.2	15.0%	0.3	2.5	29.6	11.6	21.0	44.0
Winch on the Davit has a 18kW Motor			0.0	15.0%	0.0	0.0	0.0	0.0	21.0	44.0
77 - NAVIGATION AIDS										
Aids to Navigation	1	1.8	1.8	15.0%	0.3	2.1	0.0	0.0	22.0	45.0
Foghorn	1	0.5	0.5	15.0%	0.1	0.6	0.0	0.0	22.0	45.0
80 - MAIN POWER 11KV										
Turbine Generator Package	1	71.5	71.5	15.0%	10.7	82.2	-20.9	15.1	22.0	45.0
Lube Oil Skid Details	1	13.2	13.2	15.0%	2.0	15.2	-19.7	22.2	22.0	45.0
Lube Oil Auxiliary Pump Motor A	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Lube Oil Auxiliary Pump Motor B	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Inlet Guide Vane Actuator	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Lube Oil Tank Heater	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Seal Gas Heater (Optional)	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Local Control Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Generator Contol Panel / Protection Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Generator Space Heater	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Local Control Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Turbine Generator Package	0	71.5	0.0	15.0%	0.0	0.0	20.9	15.1	22.0	45.0
Lube Oil Skid Details	0	13.2	0.0	15.0%	0.0	0.0	19.7	22.2	22.0	45.0
Lube Oil Auxiliary Pump Motor A	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Lube Oil Auxiliary Pump Motor B	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Inlet Guide Vane Actuator	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Lube Oil Tank Heater	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Seal Gas Heater (Optional)	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Local Control Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Generator Contol Panel / Protection Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Generator Space Heater	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Local Control Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Auxiliary Diesel Generator Package	1	59.4	59.4	15.0%	8.9	68.3	-20.8	-16.3	22.0	45.0
13.8 / 4.16 kV Transformer	1	15.2	15.2	15.0%	2.3	17.5	15.0	1.5	22.0	45.0
13.8 / 4.16 kV Transformer	0	15.2	0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
13.8 / .48 kV Transformer	1	5.7	5.7	15.0%	0.9	6.6	15.0	1.5	22.0	45.0
13.8 / .48 kV Transformer	0	5.7	0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
13.8 / 33 kV Step-up Transformer	1	41.1	41.1	15.0%	6.2	47.3	15.0	1.5	22.0	45.0
Tompsides Umbilical Termination Unit	1		0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
1000 HP VFD For CW and WW Pumps	1	2.0	2.0	15.0%	0.3	2.3	15.0	1.5	22.0	45.0
1000 HP VFD For CW and WW Pumps	0	2.0	0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0

5 MW Pilot Test Phase, OTEC Platform Topsides Weight Summary - Pilot Testing Condition

TOPSIDES EQUIPMENT LIST	No of units	unit wt (mt)	Net Weight (mt)	Contingency %	Contingency (mt)	TOTAL WEIGHT (mt)	CENTER OF GRAVITY X m	Y m	Z (from MWL) m	Z (from keel) m
1000 HP VFD For CW and WW Pumps	1	2.0	2.0	15.0%	0.3	2.3	15.0	1.5	22.0	45.0
1000 HP VFD For CW and WW Pumps	0	2.0	0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
300 HP VFD For Each Ramora	1	0.6	0.6	15.0%	0.1	0.7	15.0	1.5	22.0	45.0
300 HP VFD For Each Ramora	0	0.6	0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
300 HP VFD For Each Ramora	1	0.6	0.6	15.0%	0.1	0.7	15.0	1.5	22.0	45.0
300 HP VFD For Each Ramora	0	0.6	0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
1001 HP VFD For Winch Motors	1	0.6	0.6	15.0%	0.1	0.7	15.0	1.5	22.0	45.0
1001 HP VFD For Winch Motors	1	0.6	0.6	15.0%	0.1	0.7	15.0	1.5	22.0	45.0
84 - EMERGENCY POWER 480V										
Emergency Generator Package	1	22.6	22.6	15.0%	3.4	26.0	4.5	18.0	22.0	45.0
93 - BUILDINGS										
Living Quarters	1	107.8	107.8	15.0%	16.2	124.0	20.0	18.0	23.0	46.0
Living Quarters Electrical Lighing Loads	1	107.8	107.8	15.0%	16.2	124.0	11.9	21.0	22.0	45.0
Workshop / Warehouse	1	26.3	26.3	15.0%	3.9	30.2	11.2	21.0	22.0	45.0
Workshop / Warehouse Electrical Lighing Loads	1	26.3	26.3	15.0%	3.9	30.2	11.2	21.0	22.0	45.0
MCC/SWGR/CTRL Building	1	166.0	166.0	15.0%	24.9	190.9	18.1	0.0	17.0	40.0
MCC/SWGR/CTRL Building Electrical Lighing Loads	1		0.0	15.0%	0.0	0.0	18.1	0.0	16.0	39.0
97 - HVAC										
MCC Room AC Package	1	28.5	28.5	15.0%	4.3	32.8	15.7	-17.3	16.0	39.0
MCC Room AC Package Lightinh Loads	1	28.5	28.5	15.0%	4.3	32.8	15.7	-17.3	16.0	39.0
Helideck (Stairs,Landing & Support Frame is Exta)	1	17.3	17.3	15.0%	2.6	19.9	15.7	-17.3	16.0	39.0
22 - Ammonia Tank Storage										
NH3 Tanks (tanks & full fluid capacity)	1	62.0	62.0	15.0%	9.3	71.3	-12.9	0.0	16.0	39.0
NH3 Tanks (tanks & full fluid capacity)	1	62.0	62.0	15.0%	9.3	71.3	-16.0	0.0	16.0	39.0
NH3 Tanks (tanks & full fluid capacity)	1	62.0	62.0	15.0%	9.3	71.3	-19.2	0.0	16.0	39.0
NH3 Tanks (tanks & full fluid capacity)	1	62.0	62.0	15.0%	9.3	71.3	-22.3	0.0	16.0	39.0
Total Topside Utilities and Power Equipment			**1369.3**	**14.7%**	**201.0**	**1,570.3**	**3.1**	**2.9**	**20.3**	**43.3**
Topside Bulk/Piping Weight	-	-	339.5	0.0%	0.0	339.5	3.1	2.9	20.3	43.3
Topsides Structure (to be verified)										
Deck Structure	-	-	1820.0	15.0%	273.0	2093.0	0.0	0.0	17.0	40.0
Remoras Support - west	-	-	20.0	15.0%	3.0	23.0	-25.0	0.0	16.0	39.0
Remoras Support - east	-	-	20.0	15.0%	3.0	23.0	25.0	0.0	16.0	39.0
Helideck	-	-	22.0	15.0%	3.3	25.3	28.2	28.2	29.0	52.0
Total Topsides Structure			**1882.0**	**15.0%**	**282.3**	**2,164.3**	**0.3**	**0.3**	**17.1**	**40.1**
Total Topsides Weight			**3744**	**13.9%**	**522**	**4,398.6**	**1.5**	**1.4**	**19.0**	**42.0**

Note: 1. Top and bottom CWP guide weights are part of hull and will be included in hull weights.

5 MW Pilot Test Phase, OTEC Platform Topsides Weight Summary - Pilot Testing Condition

TOPSIDES EQUIPMENT LIST	No of units	unit wt (mt)	Net Weight (mt)	Contingency %	Contingency (mt)	TOTAL WEIGHT (mt)	CENTER OF GRAVITY X m	Y m	Z (from MWL) m	Z (from keel) m
Top Guide	-	rem	13.1	25.0%	3.3	16.4	0.00	0.00	-3.5	19.5
Top Guide Pads	-	remove	20.0	30.0%	6.0	26.0	0.00	0.00	-3.5	19.5
Bottom Guide	-	rem	24.0	25.0%	6.0	30.0	0.00	0.00	-33.0	-10.0
Bottom Guide Extension	-	rem	100.0	30.0%	30.0	130.0	0.00	0.00	-31.0	-8.0

2. Draft = 23.0 m

3. Elevations (from MWL)

Top Of the Column = 11.5 m
Top of the Lower Deck = 15.0 m
Top of the Upper Deck = 21.0 m

10 MW OTEC Pilot Platform Topsides Weight Summary - Fabrication Condition

TOPSIDES EQUIPMENT LIST	No of units	unit wt (mt)	Net Weight (mt)	Contingency %	Contingency (mt)	TOTAL WEIGHT (mt)	CENTER OF GRAVITY X m	Y m	Z (from MWL) m	Z (from keel) m
CWP Fabrication										
CWP Fabrication Equipment										
CWP env. Enclosure Steel Weight	-	-	136.1	15.0%	20.4	156.5	-10.7	-2.3	40.0	63.0
Enclosure Panels	-	-	18.1	15.0%	2.7	20.8	-10.7	-2.3	40.0	63.0
Live load people	20	0.091	1.8	0.0%	0.0	1.8	-10.7	-2.3	43.1	66.1
HVAC Equipment	2	1.451	2.9	15.0%	0.4	3.3	9.0	-2.5	22.0	45.0
Hydraulic HPU	-	-	1.4	15.0%	0.2	1.6	-10.7	-2.3	22.0	45.0
Total (CWP Fabrication Eqpt)			**160.3**	**14.8%**	**23.8**	**184.1**	**-10.3**	**-2.3**	**39.5**	**62.5**
CWP Fabrication Bulk Material (7 days staging supply)										
Face Sheet Rolls (Inner Rolls in 1 containers)	32	0.816	26.1	10.0%	2.6	28.7	-10.7	-2.3	44.1	67.1
Face Sheet Rolls (Outer Rolls in 1 containers)	32	0.816	26.1	10.0%	2.6	28.7	-10.7	-2.3	44.1	67.1
Pultruded Planks (5 containers)	400	0.142	56.6	10.0%	5.7	62.3	-10.7	-2.3	44.1	67.1
Container Weight	7	4.000	28.0	5.0%	1.4	29.4	-10.7	-2.3	22.0	45.0
Resin (Tote Tanks)	14	2.100	29.4	10.0%	2.9	32.3	-10.7	-2.3	44.1	67.1
Catalyst	24	0.210	5.0	10.0%	0.5	5.5	-10.7	-2.3	44.1	67.1
Promoter	3	0.224	0.7	10.0%	0.1	0.7	-10.7	-2.3	44.1	67.1
Accelerator	2	0.168	0.3	10.0%	0.0	0.4	-10.7	-2.3	44.1	67.1
RDM rolls	12	0.425	5.1	10.0%	0.5	5.6	-10.7	-2.3	44.1	67.1
Total (CWP Bulk Material)			**177.4**	**9.2%**	**16.3**	**193.7**	**-10.7**	**-2.3**	**40.8**	**63.8**
CWP Fabrication Apparatus										
CWP Fabrication Tower Apparatus			153.0	25.0%	38.3	191.3	0.0	0.0	40.0	63.0
Top Gripper structure	-	rem	20.0	25.0%	5.0	25.0	0.0	0.0	12.5	35.5
Bottom Gripper	-	rem	20.0	25.0%	5.0	25.0	0.0	0.0	4.5	27.5
Top Gripper pads	-	remove	60.0	30.0%	18.0	78.0	0.0	0.0	12.5	35.5
Bottom Gripper pads		remove	60.0	30.0%	18.0	78.0	0.0	0.0	4.5	27.5
Heave Compensator	-	rem	4.0	30.0%	1.2	5.2	0.0	0.0	17.0	40.0
Hardware & Accessories	-	remove	15.5	30.0%	4.7	20.2	0.0	0.0	17.0	40.0
Gimbal Structure	-	rem	60.0	30.0%	18.0	78.0	0.0	0.0	-3.0	20.0
Total (CWP Apparatus)			**153.0**	**25.0%**	**38.3**	**500.6**	**0.0**	**0.0**	**19.2**	**42.2**
Total CWP Fabrication eqpts.			**490.7**	**16.0%**	**78.4**	**878.4**	**-4.5**	**-1.0**	**28.2**	**51.2**
Topsides Utilities & Power Equipment										
44 - OILY WATER										
Topsides Oily Water Sump Tank	1	4.2	4.2	15.0%	0.6	4.9	0.7	14.6	16.0	39.0
Oily Water Separator	1	2.2	2.2	15.0%	0.3	2.5	2.9	15.1	16.0	39.0
50 - SEAWATER										
Seawater Lift Pump	1	5.5	5.5	15.0%	0.8	6.3	33.1	-22.7	12.5	35.5
Seawater Lift Pump	1	5.5	5.5	15.0%	0.8	6.3	33.1	-23.5	12.5	35.5
Sanitary Water Pressure Set	1	2.3	2.3	15.0%	0.3	2.6	0.0	0.0	22.0	45.0
53 - FRESH WATER										
Fresh Water Maker	1	1.98	2.0	15.0%	0.3	2.3	15.9	19.4	16.0	39.0

10 MW OTEC Pilot Platform Topsides Weight Summary - Fabrication Condition

TOPSIDES EQUIPMENT LIST	No of units	unit wt (mt)	Net Weight (mt)	Contingency %	Contingency (mt)	TOTAL WEIGHT (mt)	CENTER OF GRAVITY X m	Y m	Z (from MWL) m	Z (from keel) m
Potable Water Pressure Set	1	2.3	2.3	15.0%	0.3	2.6	15.9	22.4	16.0	39.0
Fresh Water Storage Tank	1	19.9	19.9	15.0%	3.0	22.9	15.8	14.5	16.0	39.0
Fresh Water Storage Tank	1	19.9	19.9	15.0%	3.0	22.9	19.9	14.5	16.0	39.0
Washdown Water Skid	1	1.9	1.9	15.0%	0.3	2.2	7.3	22.4	16.0	39.0
Washdown Water Pmp Motor	1	1.9	1.9	15.0%	0.3	2.2	7.3	22.4	16.0	39.0
62 - DIESEL										
Diesel Transfer Skid	1	3.0	3.0	10.0%	0.3	3.3	7.1	-19.8	22.0	45.0
Diesel Storage Tank	1	43.0	43.0	10.0%	4.3	47.3	10.2	-24.9	22.0	45.0
Diesel Storage Tank	1	43.0	43.0	10.0%	4.3	47.3	10.2	-24.9	22.0	45.0
63 - COMPRESSED AIR										
Air Compressor Skid	1	5.0	5.0	15.0%	0.8	5.8	6.5	14.5	16.0	39.0
Air Compressor	1		0.0	15.0%	0.0	0.0	6.5	14.5	16.0	39.0
Air Cooler (Radiator Type) Fan Motor	1		0.0	15.0%	0.0	0.0	6.5	14.5	16.0	39.0
Air Compressor (Standby)	1		0.0	15.0%	0.0	0.0	6.5	14.5	16.0	39.0
Air Cooler (Radiator Type) Fan Motor	1		0.0	15.0%	0.0	0.0	6.5	14.5	16.0	39.0
Instrument Air Dryer	1		0.0	15.0%	0.0	0.0	3.1	20.8	16.0	39.0
Instrument Air Receiver	1	3.2	3.2	15.0%	0.5	3.7	3.1	20.8	16.0	39.0
Utility Air Receiver	1	4.0	4.0	15.0%	0.6	4.6	0.8	21.1	16.0	39.0
Black Start Air Compressor Skid	1	2.7	2.7	15.0%	0.4	3.2	7.0	19.5	16.0	39.0
66 - SEWAGE TREATMENT										
Sewage Treatment Plant	1	1.6	1.6	15.0%	0.2	1.8	22.5	18.1	16.0	39.0
Pump 5020A Motor	1		0.0	15.0%	0.0	0.0	22.5	18.1	16.0	39.0
Pump 5020B Motor (Standby Pump Motor)	1		0.0	15.0%	0.0	0.0	22.5	18.1	16.0	39.0
Bolwer 5020C Motor	1		0.0	15.0%	0.0	0.0	22.5	18.1	16.0	39.0
71- FIREWATER										
Firewater Pump Package	1	1.1	1.1	15.0%	0.2	1.3	0.0	0.0	12.5	35.5
Firewater Pump	1		0.0	15.0%	0.0	0.0	0.0	0.0	12.5	35.5
Firewater Pump Motor			0.0	15.0%	0.0	0.0	0.0	0.0	12.5	35.5
Firewater Pump Package (Standby)	1	1.1	1.1	15.0%	0.2	1.3	0.0	0.0	12.5	35.5
Firewater Pump	1		0.0	15.0%	0.0	0.0	0.0	0.0	12.5	35.5
Firewater Pump Motor			0.0	15.0%	0.0	0.0	0.0	0.0	12.5	35.5
73 - MATERIAL HANDLING										
Pedestal Crane	1	90.0	90.0	15.0%	13.5	103.5	-10.2	25.0	27.0	50.0
Hydraulic Pump Motor										
Pedestal Crane (Lighting, A/c and Misc. Loads)										
Pedestal Crane	1	90.0	90.0	15.0%	13.5	103.5	10.2	-25.0	27.0	50.0
Hydraulic Pump Motor										
Pedestal Crane (Lighting, A/c and Misc. Loads)										
76 - SAFETY EQUIPMENT										
Survival Craft	2	4.5	9.0	15.0%	1.4	10.4	29.6	11.6	21.0	44.0
Winch on the Davit has a 25 kW 2-Speed Motor			0.0	15.0%	0.0	0.0	0.0	0.0	21.0	44.0
Survival Craft	2	4.5	9.0	15.0%	1.4	10.4	-29.6	11.6	21.0	44.0
Winch on the Davit has a 25 kW 2-Speed Motor			0.0	15.0%	0.0	0.0	0.0	0.0	21.0	44.0
Rescue Craft	1	2.2	2.2	15.0%	0.3	2.5	29.6	11.6	21.0	44.0

10 MW OTEC Pilot Platform Topsides Weight Summary - Fabrication Condition

TOPSIDES EQUIPMENT LIST	No of units	unit wt (mt)	Net Weight (mt)	Contingency %	Contingency (mt)	TOTAL WEIGHT (mt)	CENTER OF GRAVITY X m	Y m	Z (from MWL) m	Z (from keel) m
Winch on the Davit has a 18kW Motor			0.0	15.0%	0.0	0.0	0.0	0.0	21.0	44.0
77 - NAVIGATION AIDS										
Aids to Navigation	1	1.8	1.8	15.0%	0.3	2.1	0.0	0.0	22.0	45.0
Foghorn	1	0.5	0.5	15.0%	0.1	0.6	0.0	0.0	22.0	45.0
80 - MAIN POWER 11KV										
Turbine Generator Package	1	71.5	71.5	15.0%	10.7	82.2	-20.9	15.1	22.0	45.0
Lube Oil Skid Details	1	13.2	13.2	15.0%	2.0	15.2	-19.7	22.2	22.0	45.0
Lube Oil Auxiliary Pump Motor A	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Lube Oil Auxiliary Pump Motor B	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Inlet Guide Vane Actuator	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Lube Oil Tank Heater	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Seal Gas Heater (Optional)	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Local Control Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Generator Contol Panel / Protection Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Generator Space Heater	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Local Control Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Turbine Generator Package	0	71.5	0.0	15.0%	0.0	0.0	20.9	15.1	22.0	45.0
Lube Oil Skid Details	0	13.2	0.0	15.0%	0.0	0.0	19.7	22.2	22.0	45.0
Lube Oil Auxiliary Pump Motor A	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Lube Oil Auxiliary Pump Motor B	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Inlet Guide Vane Actuator	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Lube Oil Tank Heater	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Seal Gas Heater (Optional)	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Local Control Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Generator Contol Panel / Protection Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Generator Space Heater	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Local Control Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Auxiliary Diesel Generator Package	1	59.4	59.4	15.0%	8.9	68.3	-20.8	-16.3	22.0	45.0
13.8 / 4.16 kV Transformer	1	15.2	15.2	15.0%	2.3	17.5	15.0	1.5	22.0	45.0
13.8 / 4.16 kV Transformer	0	15.2	0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
13.8 / .48 kV Transformer	1	5.7	5.7	15.0%	0.9	6.6	15.0	1.5	22.0	45.0
13.8 / .48 kV Transformer	0	5.7	0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
13.8 / 33 kV Step-up Transformer	1	41.1	41.1	15.0%	6.2	47.3	15.0	1.5	22.0	45.0
Tompsides Umbilical Termination Unit	1		0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
1000 HP VFD For CW and WW Pumps	1	2.0	2.0	15.0%	0.3	2.3	15.0	1.5	22.0	45.0
1000 HP VFD For CW and WW Pumps	0	2.0	0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
1000 HP VFD For CW and WW Pumps	1	2.0	2.0	15.0%	0.3	2.3	15.0	1.5	22.0	45.0
1000 HP VFD For CW and WW Pumps	0	2.0	0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
300 HP VFD For Each Ramora	1	0.6	0.6	15.0%	0.1	0.7	15.0	1.5	22.0	45.0
300 HP VFD For Each Ramora	0	0.6	0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
300 HP VFD For Each Ramora	1	0.6	0.6	15.0%	0.1	0.7	15.0	1.5	22.0	45.0
300 HP VFD For Each Ramora	0	0.6	0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
1001 HP VFD For Winch Motors	1	0.6	0.6	15.0%	0.1	0.7	15.0	1.5	22.0	45.0
1001 HP VFD For Winch Motors	1	0.6	0.6	15.0%	0.1	0.7	15.0	1.5	22.0	45.0

10 MW OTEC Pilot Platform Topsides Weight Summary - Fabrication Condition

TOPSIDES EQUIPMENT LIST	No of units	unit wt (mt)	Net Weight (mt)	Contingency %	Contingency (mt)	TOTAL WEIGHT (mt)	CENTER OF GRAVITY X m	Y m	Z (from MWL) m	Z (from keel) m
84 - EMERGENCY POWER 480V										
Emergency Generator Package	1	22.6	22.6	15.0%	3.4	26.0	4.5	18.0	22.0	45.0
93 - BUILDINGS										
Living Quarters	1	107.8	107.8	15.0%	16.2	124.0	20.0	18.0	23.0	46.0
Living Quarters Electrical Lighing Loads	1	107.8	107.8	15.0%	16.2	124.0	11.9	21.0	22.0	45.0
Workshop / Warehouse	1	26.3	26.3	15.0%	3.9	30.2	11.2	21.0	22.0	45.0
Workshop / Warehouse Electrical Lighing Loads	1	26.3	26.3	15.0%	3.9	30.2	11.2	21.0	22.0	45.0
MCC/SWGR/CTRL Building	1	166.0	166.0	15.0%	24.9	190.9	18.1	0.0	17.0	40.0
MCC/SWGR/CTRL Building Electrical Lighing Loads	1		0.0	15.0%	0.0	0.0	18.1	0.0	16.0	39.0
97 - HVAC										
MCC Room AC Package	1	28.5	28.5	15.0%	4.3	32.8	15.7	-17.3	16.0	39.0
MCC Room AC Package Lightinh Loads	1	28.5	28.5	15.0%	4.3	32.8	15.7	-17.3	16.0	39.0
Helideck (Stairs,Landing & Support Frame is Exta)	1	17.3	17.3	15.0%	2.6	19.9	15.7	-17.3	16.0	39.0
22 - Ammonia Tank Storage										
NH3 Tanks (tanks & full fluid capacity)	1	62.0	62.0	15.0%	9.3	71.3	-12.9	0.0	16.0	39.0
NH3 Tanks (tanks & full fluid capacity)	1	62.0	62.0	15.0%	9.3	71.3	-16.0	0.0	16.0	39.0
NH3 Tanks (tanks & full fluid capacity)	1	62.0	62.0	15.0%	9.3	71.3	-19.2	0.0	16.0	39.0
NH3 Tanks (tanks & full fluid capacity)	1	62.0	62.0	15.0%	9.3	71.3	-22.3	0.0	16.0	39.0
Total Topside Utilities and Power Equipment			**1369.3**	**14.7%**	**201.0**	**1,570.3**	**3.1**	**2.9**	**20.3**	**43.3**
Topside Bulk/Piping Weight	-	-	339.5	0.0%	0.0	339.5	3.1	2.9	20.3	43.3
Topsides Structure (to be verified)										
Deck Structure	-	-	1820.0	15.0%	273.0	2093.0	0.0	0.0	17.0	40.0
Remoras Support - west	-	-	20.0	15.0%	3.0	23.0	-25.0	0.0	16.0	39.0
Remoras Support - east	-	-	20.0	15.0%	3.0	23.0	25.0	0.0	16.0	39.0
Helideck	-	-	22.0	15.0%	3.3	25.3	28.2	28.2	29.0	52.0
Total Topsides Structure			**1882.0**	**15.0%**	**282.3**	**2,164.3**	**0.3**	**0.3**	**17.1**	**40.1**
Total Topsides Weight			**4082**	**13.8%**	**562**	**4,952.6**	**0.5**	**1.1**	**20.3**	**43.3**

Note: 1. Top and bottom CWP guide weights are part of hull and will be included in hull weights.

Top Guide	-	rem	13.1	25.0%	3.3	16.4	0.00	0.00	-3.5	19.5
Top Guide Pads	-	remove	20.0	30.0%	6.0	26.0	0.00	0.00	-3.5	19.5
Bottom Guide	-	rem	24.0	25.0%	6.0	30.0	0.00	0.00	-33.0	-10.0
Bottom Guide Extension	-	rem	100.0	30.0%	30.0	130.0	0.00	0.00	-31.0	-8.0

2. Draft = 23.0 m

3. Elevations (from MWL)

Top Of the Column = 11.5 m
Top of the Lower Deck = 15.0 m
Top of the Upper Deck = 21.0 m

10 MW OTEC Pilot Platform Topsides Weight Summary - Wet Tow Condition

TOPSIDES EQUIPMENT LIST	No of units	unit wt (mt)	Net Weight (mt)	Contingency %	Contingency (mt)	TOTAL WEIGHT (mt)	CENTER OF GRAVITY X m	Y m	Z (from MWL) m	Z (from keel) m
CWP Fabrication										
CWP Fabrication Equipment										
CWP env. Enclosure Steel Weight	-	-	136.1	15.0%	20.4	156.5	-10.7	-2.3	40.0	63.0
Enclosure Panels	-	-	18.1	15.0%	2.7	20.8	-10.7	-2.3	40.0	63.0
Live load people	20	0.091	1.8	0.0%	0.0	1.8	-10.7	-2.3	43.1	66.1
HVAC Equipment	2	1.451	2.9	15.0%	0.4	3.3	9.0	-2.5	22.0	45.0
Hydraulic HPU	-	-	1.4	15.0%	0.2	1.6	-10.7	-2.3	22.0	45.0
Total (CWP Fabrication Eqpt)			**160.3**	**14.8%**	**23.8**	**184.1**	**-10.3**	**-2.3**	**39.5**	**62.5**
CWP Fabrication Bulk Material (7 days staging supply)										
Face Sheet Rolls (Inner Rolls in 1 containers)	0	0.816	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Face Sheet Rolls (Outer Rolls in 1 containers)	0	0.816	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Pultruded Planks (5 containers)	0	0.142	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Container Weight	0	4.000	0.0	5.0%	0.0	0.0	-10.7	-2.3	22.0	45.0
Resin (Tote Tanks)	0	2.100	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Catalyst	0	0.210	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Promoter	0	0.224	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Accelerator	0	0.168	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
RDM rolls	0	0.425	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Total (CWP Bulk Material)			**0.0**	**#DIV/0!**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
CWP Fabrication Apparatus										
CWP Fabrication Tower Apparatus			153.0	25.0%	38.3	191.3	0.0	0.0	40.0	63.0
Top Gripper structure	-	rem	20.0	25.0%	5.0	25.0	0.0	0.0	12.5	35.5
Bottom Gripper	-	rem	20.0	25.0%	5.0	25.0	0.0	0.0	4.5	27.5
Top Gripper pads	-	remove	60.0	30.0%	18.0	78.0	0.0	0.0	12.5	35.5
Bottom Gripper pads		remove	60.0	30.0%	18.0	78.0	0.0	0.0	4.5	27.5
Heave Compensator	-	rem	4.0	30.0%	1.2	5.2	0.0	0.0	17.0	40.0
Hardware & Accessories	-	remove	15.5	30.0%	4.7	20.2	0.0	0.0	17.0	40.0
Gimbal Structure	-	rem	60.0	30.0%	18.0	78.0	0.0	0.0	-3.0	20.0
Total (CWP Apparatus)			**153.0**	**25.0%**	**38.3**	**500.6**	**0.0**	**0.0**	**19.2**	**42.2**
Total CWP Fabrication eqpts.			**313.3**	**19.8%**	**62.0**	**684.7**	**-2.8**	**-0.6**	**24.6**	**47.6**
Topsides Utilities & Power Equipment										
44 - OILY WATER										
Topsides Oily Water Sump Tank	1	4.2	4.2	15.0%	0.6	4.9	0.7	14.6	16.0	39.0
Oily Water Separator	1	2.2	2.2	15.0%	0.3	2.5	2.9	15.1	16.0	39.0
50 - SEAWATER										
Seawater Lift Pump	1	5.5	5.5	15.0%	0.8	6.3	33.1	-22.7	12.5	35.5
Seawater Lift Pump	1	5.5	5.5	15.0%	0.8	6.3	33.1	-23.5	12.5	35.5
Sanitary Water Pressure Set	1	2.3	2.3	15.0%	0.3	2.6	0.0	0.0	22.0	45.0
53 - FRESH WATER										
Fresh Water Maker	1	1.98	2.0	15.0%	0.3	2.3	15.9	19.4	16.0	39.0

10 MW OTEC Pilot Platform Topsides Weight Summary - Wet Tow Condition

TOPSIDES EQUIPMENT LIST	No of units	unit wt (mt)	Net Weight (mt)	Contingency %	Contingency (mt)	TOTAL WEIGHT (mt)	CENTER OF GRAVITY X m	Y m	Z (from MWL) m	Z (from keel) m
Potable Water Pressure Set	1	2.3	2.3	15.0%	0.3	2.6	15.9	22.4	16.0	39.0
Fresh Water Storage Tank	1	19.9	19.9	15.0%	3.0	22.9	15.8	14.5	16.0	39.0
Fresh Water Storage Tank	1	19.9	19.9	15.0%	3.0	22.9	19.9	14.5	16.0	39.0
Washdown Water Skid	1	1.9	1.9	15.0%	0.3	2.2	7.3	22.4	16.0	39.0
Washdown Water Pmp Motor	1	1.9	1.9	15.0%	0.3	2.2	7.3	22.4	16.0	39.0
62 - DIESEL										
Diesel Transfer Skid	1	3.0	3.0	10.0%	0.3	3.3	7.1	-19.8	22.0	45.0
Diesel Storage Tank	1	43.0	43.0	10.0%	4.3	47.3	10.2	-24.9	22.0	45.0
Diesel Storage Tank	1	43.0	43.0	10.0%	4.3	47.3	10.2	-24.9	22.0	45.0
63 - COMPRESSED AIR										
Air Compressor Skid	1	5.0	5.0	15.0%	0.8	5.8	6.5	14.5	16.0	39.0
Air Compressor	1		0.0	15.0%	0.0	0.0	6.5	14.5	16.0	39.0
Air Cooler (Radiator Type) Fan Motor	1		0.0	15.0%	0.0	0.0	6.5	14.5	16.0	39.0
Air Compressor (Standby)	1		0.0	15.0%	0.0	0.0	6.5	14.5	16.0	39.0
Air Cooler (Radiator Type) Fan Motor	1		0.0	15.0%	0.0	0.0	6.5	14.5	16.0	39.0
Instrument Air Dryer	1		0.0	15.0%	0.0	0.0	3.1	20.8	16.0	39.0
Instrument Air Receiver	1	3.2	3.2	15.0%	0.5	3.7	3.1	20.8	16.0	39.0
Utility Air Receiver	1	4.0	4.0	15.0%	0.6	4.6	0.8	21.1	16.0	39.0
Black Start Air Compressor Skid	1	2.7	2.7	15.0%	0.4	3.2	7.0	19.5	16.0	39.0
66 - SEWAGE TREATMENT										
Sewage Treatment Plant	1	1.6	1.6	15.0%	0.2	1.8	22.5	18.1	16.0	39.0
Pump 5020A Motor	1		0.0	15.0%	0.0	0.0	22.5	18.1	16.0	39.0
Pump 5020B Motor (Standby Pump Motor)	1		0.0	15.0%	0.0	0.0	22.5	18.1	16.0	39.0
Bolwer 5020C Motor	1		0.0	15.0%	0.0	0.0	22.5	18.1	16.0	39.0
71- FIREWATER										
Firewater Pump Package	1	1.1	1.1	15.0%	0.2	1.3	0.0	0.0	12.5	35.5
Firewater Pump	1		0.0	15.0%	0.0	0.0	0.0	0.0	12.5	35.5
Firewater Pump Motor			0.0	15.0%	0.0	0.0	0.0	0.0	12.5	35.5
Firewater Pump Package (Standby)	1	1.1	1.1	15.0%	0.2	1.3	0.0	0.0	12.5	35.5
Firewater Pump	1		0.0	15.0%	0.0	0.0	0.0	0.0	12.5	35.5
Firewater Pump Motor			0.0	15.0%	0.0	0.0	0.0	0.0	12.5	35.5
73 - MATERIAL HANDLING										
Pedestal Crane	1	90.0	90.0	15.0%	13.5	103.5	-10.2	25.0	27.0	50.0
Hydraulic Pump Motor										
Pedestal Crane (Lighting, A/c and Misc. Loads)										
Pedestal Crane	1	90.0	90.0	15.0%	13.5	103.5	10.2	-25.0	27.0	50.0
Hydraulic Pump Motor										
Pedestal Crane (Lighting, A/c and Misc. Loads)										
76 - SAFETY EQUIPMENT										
Survival Craft	2	4.5	9.0	15.0%	1.4	10.4	29.6	11.6	21.0	44.0
Winch on the Davit has a 25 kW 2-Speed Motor			0.0	15.0%	0.0	0.0	0.0	0.0	21.0	44.0
Survival Craft	2	4.5	9.0	15.0%	1.4	10.4	-29.6	11.6	21.0	44.0
Winch on the Davit has a 25 kW 2-Speed Motor			0.0	15.0%	0.0	0.0	0.0	0.0	21.0	44.0
Rescue Craft	1	2.2	2.2	15.0%	0.3	2.5	29.6	11.6	21.0	44.0

10 MW OTEC Pilot Platform Topsides Weight Summary - Wet Tow Condition

TOPSIDES EQUIPMENT LIST	No of units	unit wt (mt)	Net Weight (mt)	Contingency %	Contingency (mt)	TOTAL WEIGHT (mt)	CENTER OF GRAVITY X m	Y m	Z (from MWL) m	Z (from keel) m
Winch on the Davit has a 18kW Motor			0.0	15.0%	0.0	0.0	0.0	0.0	21.0	44.0
77 - NAVIGATION AIDS										
Aids to Navigation	1	1.8	1.8	15.0%	0.3	2.1	0.0	0.0	22.0	45.0
Foghorn	1	0.5	0.5	15.0%	0.1	0.6	0.0	0.0	22.0	45.0
80 - MAIN POWER 11KV										
Turbine Generator Package	1	71.5	71.5	15.0%	10.7	82.2	-20.9	15.1	22.0	45.0
Lube Oil Skid Details	1	13.2	13.2	15.0%	2.0	15.2	-19.7	22.2	22.0	45.0
Lube Oil Auxiliary Pump Motor A	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Lube Oil Auxiliary Pump Motor B	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Inlet Guide Vane Actuator	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Lube Oil Tank Heater	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Seal Gas Heater (Optional)	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Local Control Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Generator Contol Panel / Protection Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Generator Space Heater	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Local Control Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Turbine Generator Package	0	71.5	0.0	15.0%	0.0	0.0	20.9	15.1	22.0	45.0
Lube Oil Skid Details	0	13.2	0.0	15.0%	0.0	0.0	19.7	22.2	22.0	45.0
Lube Oil Auxiliary Pump Motor A	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Lube Oil Auxiliary Pump Motor B	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Inlet Guide Vane Actuator	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Lube Oil Tank Heater	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Seal Gas Heater (Optional)	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Local Control Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Generator Contol Panel / Protection Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Generator Space Heater	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Local Control Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Auxiliary Diesel Generator Package	1	59.4	59.4	15.0%	8.9	68.3	-20.8	-16.3	22.0	45.0
13.8 / 4.16 kV Transformer	1	15.2	15.2	15.0%	2.3	17.5	15.0	1.5	22.0	45.0
13.8 / 4.16 kV Transformer	0	15.2	0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
13.8 / .48 kV Transformer	1	5.7	5.7	15.0%	0.9	6.6	15.0	1.5	22.0	45.0
13.8 / .48 kV Transformer	0	5.7	0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
13.8 / 33 kV Step-up Transformer	1	41.1	41.1	15.0%	6.2	47.3	15.0	1.5	22.0	45.0
Tompsides Umbilical Termination Unit	1		0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
1000 HP VFD For CW and WW Pumps	1	2.0	2.0	15.0%	0.3	2.3	15.0	1.5	22.0	45.0
1000 HP VFD For CW and WW Pumps	0	2.0	0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
1000 HP VFD For CW and WW Pumps	1	2.0	2.0	15.0%	0.3	2.3	15.0	1.5	22.0	45.0
1000 HP VFD For CW and WW Pumps	0	2.0	0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
300 HP VFD For Each Ramora	1	0.6	0.6	15.0%	0.1	0.7	15.0	1.5	22.0	45.0
300 HP VFD For Each Ramora	0	0.6	0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
300 HP VFD For Each Ramora	1	0.6	0.6	15.0%	0.1	0.7	15.0	1.5	22.0	45.0
300 HP VFD For Each Ramora	0	0.6	0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
1001 HP VFD For Winch Motors	1	0.6	0.6	15.0%	0.1	0.7	15.0	1.5	22.0	45.0
1001 HP VFD For Winch Motors	1	0.6	0.6	15.0%	0.1	0.7	15.0	1.5	22.0	45.0

10 MW OTEC Pilot Platform Topsides Weight Summary - Wet Tow Condition

TOPSIDES EQUIPMENT LIST	No of units	unit wt (mt)	Net Weight (mt)	Contingency %	Contingency (mt)	TOTAL WEIGHT (mt)	CENTER OF GRAVITY X m	Y m	Z (from MWL) m	Z (from keel) m
84 - EMERGENCY POWER 480V										
Emergency Generator Package	1	22.6	22.6	15.0%	3.4	26.0	4.5	18.0	22.0	45.0
93 - BUILDINGS										
Living Quarters	1	107.8	107.8	15.0%	16.2	124.0	20.0	18.0	23.0	46.0
Living Quarters Electrical Lighing Loads	1	107.8	107.8	15.0%	16.2	124.0	11.9	21.0	22.0	45.0
Workshop / Warehouse	1	26.3	26.3	15.0%	3.9	30.2	11.2	21.0	22.0	45.0
Workshop / Warehouse Electrical Lighing Loads	1	26.3	26.3	15.0%	3.9	30.2	11.2	21.0	22.0	45.0
MCC/SWGR/CTRL Building	1	166.0	166.0	15.0%	24.9	190.9	18.1	0.0	17.0	40.0
MCC/SWGR/CTRL Building Electrical Lighing Loads	1		0.0	15.0%	0.0	0.0	18.1	0.0	16.0	39.0
97 - HVAC										
MCC Room AC Package	1	28.5	28.5	15.0%	4.3	32.8	15.7	-17.3	16.0	39.0
MCC Room AC Package Lightinh Loads	1	28.5	28.5	15.0%	4.3	32.8	15.7	-17.3	16.0	39.0
Helideck (Stairs,Landing & Support Frame is Exta)	1	17.3	17.3	15.0%	2.6	19.9	15.7	-17.3	16.0	39.0
22 - Ammonia Tank Storage										
NH3 Tanks (tanks & full fluid capacity)	1	62.0	62.0	15.0%	9.3	71.3	-12.9	0.0	16.0	39.0
NH3 Tanks (tanks & full fluid capacity)	1	62.0	62.0	15.0%	9.3	71.3	-16.0	0.0	16.0	39.0
NH3 Tanks (tanks & full fluid capacity)	1	62.0	62.0	15.0%	9.3	71.3	-19.2	0.0	16.0	39.0
NH3 Tanks (tanks & full fluid capacity)	1	62.0	62.0	15.0%	9.3	71.3	-22.3	0.0	16.0	39.0
Total Topside Utilities and Power Equipment			**1369.3**	**14.7%**	**201.0**	**1,570.3**	**3.1**	**2.9**	**20.3**	**43.3**
Topside Bulk/Piping Weight	-	-	339.5	0.0%	0.0	339.5	3.1	2.9	20.3	43.3
Topsides Structure (to be verified)										
Deck Structure	-	-	1820.0	15.0%	273.0	2093.0	0.0	0.0	17.0	40.0
Remoras Support - west	-	-	20.0	15.0%	3.0	23.0	-25.0	0.0	16.0	39.0
Remoras Support - east	-	-	20.0	15.0%	3.0	23.0	25.0	0.0	16.0	39.0
Helideck	-	-	22.0	15.0%	3.3	25.3	28.2	28.2	29.0	52.0
Total Topsides Structure			**1882.0**	**15.0%**	**282.3**	**2,164.3**	**0.3**	**0.3**	**17.1**	**40.1**
Total Topsides Weight			**3904**	**14.0%**	**545**	**4,758.8**	**1.0**	**1.2**	**19.5**	**42.5**

Note: 1. Top and bottom CWP guide weights are part of hull and will be included in hull weights.

Top Guide	-	rem	13.1	25.0%	3.3	16.4	0.00	0.00	-3.5	19.5
Top Guide Pads	-	remove	20.0	30.0%	6.0	26.0	0.00	0.00	-3.5	19.5
Bottom Guide	-	rem	24.0	25.0%	6.0	30.0	0.00	0.00	-33.0	-10.0
Bottom Guide Extension	-	rem	100.0	30.0%	30.0	130.0	0.00	0.00	-31.0	-8.0

2. Draft = 23.0 m

3. Elevations (from MWL)

Top Of the Column = 11.5 m
Top of the Lower Deck = 15.0 m
Top of the Upper Deck = 21.0 m

10 MW OTEC Pilot Platform Topsides Weight Summary - Lightship Condition

TOPSIDES EQUIPMENT LIST	No of units	unit wt (mt)	Net Weight (mt)	Contingency %	Contingency (mt)	TOTAL WEIGHT (mt)	CENTER OF GRAVITY X m	Y m	Z (from MWL) m	Z (from keel) m
CWP Fabrication										
CWP Fabrication Equipment										
CWP env. Enclosure Steel Weight	-	-	136.1	15.0%	20.4	156.5	-10.7	-2.3	40.0	63.0
Enclosure Panels	-	-	18.1	15.0%	2.7	20.8	-10.7	-2.3	40.0	63.0
Live load people	20	0.091	1.8	0.0%	0.0	1.8	-10.7	-2.3	43.1	66.1
HVAC Equipment	2	1.451	2.9	15.0%	0.4	3.3	9.0	-2.5	22.0	45.0
Hydraulic HPU	-	-	1.4	15.0%	0.2	1.6	-10.7	-2.3	22.0	45.0
Total (CWP Fabrication Eqpt)			**160.3**	**14.8%**	**23.8**	**184.1**	**-10.3**	**-2.3**	**39.5**	**62.5**
CWP Fabrication Bulk Material (7 days staging supply)										
Face Sheet Rolls (Inner Rolls in 1 containers)	0	0.816	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Face Sheet Rolls (Outer Rolls in 1 containers)	0	0.816	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Pultruded Planks (5 containers)	0	0.142	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Container Weight	0	4.000	0.0	5.0%	0.0	0.0	-10.7	-2.3	22.0	45.0
Resin (Tote Tanks)	0	2.100	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Catalyst	0	0.210	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Promoter	0	0.224	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Accelerator	0	0.168	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
RDM rolls	0	0.425	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Total (CWP Bulk Material)			**0.0**	**#DIV/0!**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
CWP Fabrication Apparatus										
CWP Fabrication Tower Apparatus			153.0	25.0%	38.3	191.3	0.0	0.0	40.0	63.0
Top Gripper structure	-	rem	20.0	25.0%	5.0	25.0	0.0	0.0	12.5	35.5
Bottom Gripper	-	rem	20.0	25.0%	5.0	25.0	0.0	0.0	4.5	27.5
Top Gripper pads	-	remove	60.0	30.0%	18.0	78.0	0.0	0.0	12.5	35.5
Bottom Gripper pads		remove	60.0	30.0%	18.0	78.0	0.0	0.0	4.5	27.5
Heave Compensator	-	rem	4.0	30.0%	1.2	5.2	0.0	0.0	17.0	40.0
Hardware & Accessories	-	remove	15.5	30.0%	4.7	20.2	0.0	0.0	17.0	40.0
Gimbal Structure	-	rem	60.0	30.0%	18.0	78.0	0.0	0.0	-3.0	20.0
Total (CWP Apparatus)			**153.0**	**25.0%**	**38.3**	**500.6**	**0.0**	**0.0**	**19.2**	**42.2**
Total CWP Fabrication eqpts.			**313.3**	**19.8%**	**62.0**	**684.7**	**-2.8**	**-0.6**	**24.6**	**47.6**
Topsides Utilities & Power Equipment										
44 - OILY WATER										
Topsides Oily Water Sump Tank	1	4.2	4.2	15.0%	0.6	4.9	0.7	14.6	16.0	39.0
Oily Water Separator	1	2.2	2.2	15.0%	0.3	2.5	2.9	15.1	16.0	39.0
50 - SEAWATER										
Seawater Lift Pump	1	5.5	5.5	15.0%	0.8	6.3	33.1	-22.7	12.5	35.5
Seawater Lift Pump	1	5.5	5.5	15.0%	0.8	6.3	33.1	-23.5	12.5	35.5
Sanitary Water Pressure Set	1	2.3	2.3	15.0%	0.3	2.6	0.0	0.0	22.0	45.0
53 - FRESH WATER										
Fresh Water Maker	1	1.98	2.0	15.0%	0.3	2.3	15.9	19.4	16.0	39.0

10 MW OTEC Pilot Platform Topsides Weight Summary - Lightship Condition

TOPSIDES EQUIPMENT LIST	No of units	unit wt (mt)	Net Weight (mt)	Contingency %	Contingency (mt)	TOTAL WEIGHT (mt)	CENTER OF GRAVITY X m	Y m	Z (from MWL) m	Z (from keel) m
Potable Water Pressure Set	1	2.3	2.3	15.0%	0.3	2.6	15.9	22.4	16.0	39.0
Fresh Water Storage Tank	1	19.9	19.9	15.0%	3.0	22.9	15.8	14.5	16.0	39.0
Fresh Water Storage Tank	1	19.9	19.9	15.0%	3.0	22.9	19.9	14.5	16.0	39.0
Washdown Water Skid	1	1.9	1.9	15.0%	0.3	2.2	7.3	22.4	16.0	39.0
Washdown Water Pmp Motor	1	1.9	1.9	15.0%	0.3	2.2	7.3	22.4	16.0	39.0
62 - DIESEL										
Diesel Transfer Skid	1	3.0	3.0	10.0%	0.3	3.3	7.1	-19.8	22.0	45.0
Diesel Storage Tank	1	43.0	43.0	10.0%	4.3	47.3	10.2	-24.9	22.0	45.0
Diesel Storage Tank	1	43.0	43.0	10.0%	4.3	47.3	10.2	-24.9	22.0	45.0
63 - COMPRESSED AIR										
Air Compressor Skid	1	5.0	5.0	15.0%	0.8	5.8	6.5	14.5	16.0	39.0
Air Compressor	1		0.0	15.0%	0.0	0.0	6.5	14.5	16.0	39.0
Air Cooler (Radiator Type) Fan Motor	1		0.0	15.0%	0.0	0.0	6.5	14.5	16.0	39.0
Air Compressor (Standby)	1		0.0	15.0%	0.0	0.0	6.5	14.5	16.0	39.0
Air Cooler (Radiator Type) Fan Motor	1		0.0	15.0%	0.0	0.0	6.5	14.5	16.0	39.0
Instrument Air Dryer	1		0.0	15.0%	0.0	0.0	3.1	20.8	16.0	39.0
Instrument Air Receiver	1	3.2	3.2	15.0%	0.5	3.7	3.1	20.8	16.0	39.0
Utility Air Receiver	1	4.0	4.0	15.0%	0.6	4.6	0.8	21.1	16.0	39.0
Black Start Air Compressor Skid	1	2.7	2.7	15.0%	0.4	3.2	7.0	19.5	16.0	39.0
66 - SEWAGE TREATMENT										
Sewage Treatment Plant	1	1.6	1.6	15.0%	0.2	1.8	22.5	18.1	16.0	39.0
Pump 5020A Motor	1		0.0	15.0%	0.0	0.0	22.5	18.1	16.0	39.0
Pump 5020B Motor (Standby Pump Motor)	1		0.0	15.0%	0.0	0.0	22.5	18.1	16.0	39.0
Bolwer 5020C Motor	1		0.0	15.0%	0.0	0.0	22.5	18.1	16.0	39.0
71- FIREWATER										
Firewater Pump Package	1	1.1	1.1	15.0%	0.2	1.3	0.0	0.0	12.5	35.5
Firewater Pump	1		0.0	15.0%	0.0	0.0	0.0	0.0	12.5	35.5
Firewater Pump Motor			0.0	15.0%	0.0	0.0	0.0	0.0	12.5	35.5
Firewater Pump Package (Standby)	1	1.1	1.1	15.0%	0.2	1.3	0.0	0.0	12.5	35.5
Firewater Pump	1		0.0	15.0%	0.0	0.0	0.0	0.0	12.5	35.5
Firewater Pump Motor			0.0	15.0%	0.0	0.0	0.0	0.0	12.5	35.5
73 - MATERIAL HANDLING										
Pedestal Crane	1	90.0	90.0	15.0%	13.5	103.5	-10.2	25.0	27.0	50.0
Hydraulic Pump Motor										
Pedestal Crane (Lighting, A/c and Misc. Loads)										
Pedestal Crane	1	90.0	90.0	15.0%	13.5	103.5	10.2	-25.0	27.0	50.0
Hydraulic Pump Motor										
Pedestal Crane (Lighting, A/c and Misc. Loads)										
76 - SAFETY EQUIPMENT										
Survival Craft	2	4.5	9.0	15.0%	1.4	10.4	29.6	11.6	21.0	44.0
Winch on the Davit has a 25 kW 2-Speed Motor			0.0	15.0%	0.0	0.0	0.0	0.0	21.0	44.0
Survival Craft	2	4.5	9.0	15.0%	1.4	10.4	-29.6	11.6	21.0	44.0
Winch on the Davit has a 25 kW 2-Speed Motor			0.0	15.0%	0.0	0.0	0.0	0.0	21.0	44.0
Rescue Craft	1	2.2	2.2	15.0%	0.3	2.5	29.6	11.6	21.0	44.0

10 MW OTEC Pilot Platform Topsides Weight Summary - Lightship Condition

TOPSIDES EQUIPMENT LIST	No of units	unit wt (mt)	Net Weight (mt)	Contingency %	Contingency (mt)	TOTAL WEIGHT (mt)	CENTER OF GRAVITY X m	Y m	Z (from MWL) m	Z (from keel) m
Winch on the Davit has a 18kW Motor			0.0	15.0%	0.0	0.0	0.0	0.0	21.0	44.0
77 - NAVIGATION AIDS										
Aids to Navigation	1	1.8	1.8	15.0%	0.3	2.1	0.0	0.0	22.0	45.0
Foghorn	1	0.5	0.5	15.0%	0.1	0.6	0.0	0.0	22.0	45.0
80 - MAIN POWER 11KV										
Turbine Generator Package	1	71.5	71.5	15.0%	10.7	82.2	-20.9	15.1	22.0	45.0
Lube Oil Skid Details	1	13.2	13.2	15.0%	2.0	15.2	-19.7	22.2	22.0	45.0
Lube Oil Auxiliary Pump Motor A	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Lube Oil Auxiliary Pump Motor B	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Inlet Guide Vane Actuator	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Lube Oil Tank Heater	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Seal Gas Heater (Optional)	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Local Control Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Generator Contol Panel / Protection Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Generator Space Heater	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Local Control Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Turbine Generator Package	0	71.5	0.0	15.0%	0.0	0.0	20.9	15.1	22.0	45.0
Lube Oil Skid Details	0	13.2	0.0	15.0%	0.0	0.0	19.7	22.2	22.0	45.0
Lube Oil Auxiliary Pump Motor A	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Lube Oil Auxiliary Pump Motor B	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Inlet Guide Vane Actuator	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Lube Oil Tank Heater	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Seal Gas Heater (Optional)	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Local Control Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Generator Contol Panel / Protection Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Generator Space Heater	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Local Control Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Auxiliary Diesel Generator Package	1	59.4	59.4	15.0%	8.9	68.3	-20.8	-16.3	22.0	45.0
13.8 / 4.16 kV Transformer	1	15.2	15.2	15.0%	2.3	17.5	15.0	1.5	22.0	45.0
13.8 / 4.16 kV Transformer	0	15.2	0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
13.8 / .48 kV Transformer	1	5.7	5.7	15.0%	0.9	6.6	15.0	1.5	22.0	45.0
13.8 / .48 kV Transformer	0	5.7	0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
13.8 / 33 kV Step-up Transformer	1	41.1	41.1	15.0%	6.2	47.3	15.0	1.5	22.0	45.0
Tompsides Umbilical Termination Unit	1		0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
1000 HP VFD For CW and WW Pumps	1	2.0	2.0	15.0%	0.3	2.3	15.0	1.5	22.0	45.0
1000 HP VFD For CW and WW Pumps	0	2.0	0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
1000 HP VFD For CW and WW Pumps	1	2.0	2.0	15.0%	0.3	2.3	15.0	1.5	22.0	45.0
1000 HP VFD For CW and WW Pumps	0	2.0	0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
300 HP VFD For Each Ramora	1	0.6	0.6	15.0%	0.1	0.7	15.0	1.5	22.0	45.0
300 HP VFD For Each Ramora	0	0.6	0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
300 HP VFD For Each Ramora	1	0.6	0.6	15.0%	0.1	0.7	15.0	1.5	22.0	45.0
300 HP VFD For Each Ramora	0	0.6	0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
1001 HP VFD For Winch Motors	1	0.6	0.6	15.0%	0.1	0.7	15.0	1.5	22.0	45.0
1001 HP VFD For Winch Motors	1	0.6	0.6	15.0%	0.1	0.7	15.0	1.5	22.0	45.0

10 MW OTEC Pilot Platform Topsides Weight Summary - Lightship Condition

TOPSIDES EQUIPMENT LIST	No of units	unit wt (mt)	Net Weight (mt)	Contingency %	Contingency (mt)	TOTAL WEIGHT (mt)	CENTER OF GRAVITY X m	Y m	Z (from MWL) m	Z (from keel) m
84 - EMERGENCY POWER 480V										
Emergency Generator Package	1	22.6	22.6	15.0%	3.4	26.0	4.5	18.0	22.0	45.0
93 - BUILDINGS										
Living Quarters	1	107.8	107.8	15.0%	16.2	124.0	20.0	18.0	23.0	46.0
Living Quarters Electrical Lighing Loads	1	107.8	107.8	15.0%	16.2	124.0	11.9	21.0	22.0	45.0
Workshop / Warehouse	1	26.3	26.3	15.0%	3.9	30.2	11.2	21.0	22.0	45.0
Workshop / Warehouse Electrical Lighing Loads	1	26.3	26.3	15.0%	3.9	30.2	11.2	21.0	22.0	45.0
MCC/SWGR/CTRL Building	1	166.0	166.0	15.0%	24.9	190.9	18.1	0.0	17.0	40.0
MCC/SWGR/CTRL Building Electrical Lighing Loads	1		0.0	15.0%	0.0	0.0	18.1	0.0	16.0	39.0
97 - HVAC										
MCC Room AC Package	1	28.5	28.5	15.0%	4.3	32.8	15.7	-17.3	16.0	39.0
MCC Room AC Package Lightinh Loads	1	28.5	28.5	15.0%	4.3	32.8	15.7	-17.3	16.0	39.0
Helideck (Stairs,Landing & Support Frame is Exta)	1	17.3	17.3	15.0%	2.6	19.9	15.7	-17.3	16.0	39.0
22 - Ammonia Tank Storage										
NH3 Tanks (tanks & full fluid capacity)	1	62.0	62.0	15.0%	9.3	71.3	-12.9	0.0	16.0	39.0
NH3 Tanks (tanks & full fluid capacity)	1	62.0	62.0	15.0%	9.3	71.3	-16.0	0.0	16.0	39.0
NH3 Tanks (tanks & full fluid capacity)	1	62.0	62.0	15.0%	9.3	71.3	-19.2	0.0	16.0	39.0
NH3 Tanks (tanks & full fluid capacity)	1	62.0	62.0	15.0%	9.3	71.3	-22.3	0.0	16.0	39.0
Total Topside Utilities and Power Equipment			**1369.3**	**14.7%**	**201.0**	**1,570.3**	**3.1**	**2.9**	**20.3**	**43.3**
Topside Bulk/Piping Weight	-	-	339.5	0.0%	0.0	339.5	3.1	2.9	20.3	43.3
Topsides Structure (to be verified)										
Deck Structure	-	-	1820.0	15.0%	273.0	2093.0	0.0	0.0	17.0	40.0
Remoras Support - west	-	-	20.0	15.0%	3.0	23.0	-25.0	0.0	16.0	39.0
Remoras Support - east	-	-	20.0	15.0%	3.0	23.0	25.0	0.0	16.0	39.0
Helideck	-	-	22.0	15.0%	3.3	25.3	28.2	28.2	29.0	52.0
Total Topsides Structure			**1882.0**	**15.0%**	**282.3**	**2,164.3**	**0.3**	**0.3**	**17.1**	**40.1**
Total Topsides Weight			**3904**	**14.0%**	**545**	**4,758.8**	**1.0**	**1.2**	**19.5**	**42.5**

Note: 1. Top and bottom CWP guide weights are part of hull and will be included in hull weights.

Top Guide	-	rem	13.1	25.0%	3.3	16.4	0.00	0.00	#REF!	19.5
Top Guide Pads	-	remove	20.0	30.0%	6.0	26.0	0.00	0.00	#REF!	19.5
Bottom Guide	-	rem	24.0	25.0%	6.0	30.0	0.00	0.00	#REF!	-10.0
Bottom Guide Extension	-	rem	100.0	30.0%	30.0	130.0	0.00	0.00	#REF!	-8.0

2. Draft = 23.0 m

3. Elevations (from MWL)

Top Of the Column = 11.5 m
Top of the Lower Deck = 15.0 m
Top of the Upper Deck = 21.0 m

10 MW Full Production Phase, OTEC Platform Topsides Weight Summary - Full Production Condition

TOPSIDES EQUIPMENT LIST	No of units	unit wt (mt)	Net Weight (mt)	Contingency %	Contingency (mt)	TOTAL WEIGHT (mt)	CENTER OF GRAVITY X m	Y m	Z (from MWL) m	Z (from keel) m
CWP Fabrication										
CWP Fabrication Equipment										
CWP env. Enclosure Steel Weight	-	-	0.0	15.0%	0.0	0.0	-10.7	-2.3	40.0	63.0
Enclosure Panels	-	-	0.0	15.0%	0.0	0.0	-10.7	-2.3	40.0	63.0
Live load people	20	0.091	0.0	0.0%	0.0	0.0	-10.7	-2.3	43.1	66.1
HVAC Equipment	2	1.451	0.0	15.0%	0.0	0.0	9.0	-2.5	22.0	45.0
Hydraulic HPU	-	-	0.0	15.0%	0.0	0.0	-10.7	-2.3	22.0	45.0
Total (CWP Fabrication Eqpt)			**0.0**	**#DIV/0!**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
CWP Fabrication Bulk Material (7 days staging supply)										
Face Sheet Rolls (Inner Rolls in 1 containers)	0	0.816	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Face Sheet Rolls (Outer Rolls in 1 containers)	0	0.816	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Pultruded Planks (5 containers)	0	0.142	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Container Weight	0	4.000	0.0	5.0%	0.0	0.0	-10.7	-2.3	22.0	45.0
Resin (Tote Tanks)	0	2.100	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Catalyst	0	0.210	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Promoter	0	0.224	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Accelerator	0	0.168	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
RDM rolls	0	0.425	0.0	10.0%	0.0	0.0	-10.7	-2.3	44.1	67.1
Total (CWP Bulk Material)			**0.0**	**#DIV/0!**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
CWP Fabrication Apparatus										
CWP Fabrication Tower Apparatus			153.0	25.0%	38.3	191.3	0.0	0.0	40.0	63.0
Top Gripper structure	-	rem	20.0	25.0%	5.0	25.0	0.0	0.0	12.5	35.5
Bottom Gripper	-	rem	20.0	25.0%	5.0	25.0	0.0	0.0	4.5	27.5
Top Gripper pads	-	remove	0.0	30.0%	0.0	0.0	0.0	0.0	12.5	35.5
Bottom Gripper pads		remove	0.0	30.0%	0.0	0.0	0.0	0.0	4.5	27.5
Heave Compensator	-	rem	4.0	30.0%	1.2	5.2	0.0	0.0	17.0	40.0
Hardware & Accessories	-	remove	0.0	30.0%	0.0	0.0	0.0	0.0	17.0	40.0
Gimbal Structure	-	rem	60.0	30.0%	18.0	78.0	0.0	0.0	-3.0	20.0
Total (CWP Apparatus)			**153.0**	**25.0%**	**38.3**	**324.5**	**0.0**	**0.0**	**24.4**	**47.4**
Total CWP Fabrication eqpts.			**153.0**	**25.0%**	**38.3**	**324.5**	**0.0**	**0.0**	**24.4**	**47.4**
Topsides Utilities & Power Equipment										
44 - OILY WATER										
Topsides Oily Water Sump Tank	1	4.2	4.2	15.0%	0.6	4.9	0.7	14.6	16.0	39.0
Oily Water Separator	1	2.2	2.2	15.0%	0.3	2.5	2.9	15.1	16.0	39.0
50 - SEAWATER										
Seawater Lift Pump	1	5.5	5.5	15.0%	0.8	6.3	33.1	-22.7	12.5	35.5
Seawater Lift Pump	1	5.5	5.5	15.0%	0.8	6.3	33.1	-23.5	12.5	35.5
Sanitary Water Pressure Set	1	2.3	2.3	15.0%	0.3	2.6	0.0	0.0	22.0	45.0
53 - FRESH WATER										
Fresh Water Maker	1	1.98	2.0	15.0%	0.3	2.3	15.9	19.4	16.0	39.0

10 MW Full Production Phase, OTEC Platform Topsides Weight Summary - Full Production Condition

TOPSIDES EQUIPMENT LIST	No of units	unit wt (mt)	Net Weight (mt)	Contingency %	Contingency (mt)	TOTAL WEIGHT (mt)	CENTER OF GRAVITY X m	Y m	Z (from MWL) m	Z (from keel) m
Potable Water Pressure Set	1	2.3	2.3	15.0%	0.3	2.6	15.9	22.4	16.0	39.0
Fresh Water Storage Tank	1	19.9	19.9	15.0%	3.0	22.9	15.8	14.5	16.0	39.0
Fresh Water Storage Tank	1	19.9	19.9	15.0%	3.0	22.9	19.9	14.5	16.0	39.0
Washdown Water Skid	1	1.9	1.9	15.0%	0.3	2.2	7.3	22.4	16.0	39.0
Washdown Water Pmp Motor	1	1.9	1.9	15.0%	0.3	2.2	7.3	22.4	16.0	39.0
62 - DIESEL										
Diesel Transfer Skid	1	3.0	3.0	10.0%	0.3	3.3	7.1	-19.8	22.0	45.0
Diesel Storage Tank	1	43.0	43.0	10.0%	4.3	47.3	10.2	-24.9	22.0	45.0
Diesel Storage Tank	1	43.0	43.0	10.0%	4.3	47.3	10.2	-24.9	22.0	45.0
63 - COMPRESSED AIR										
Air Compressor Skid	1	5.0	5.0	15.0%	0.8	5.8	6.5	14.5	16.0	39.0
Air Compressor	1		0.0	15.0%	0.0	0.0	6.5	14.5	16.0	39.0
Air Cooler (Radiator Type) Fan Motor	1		0.0	15.0%	0.0	0.0	6.5	14.5	16.0	39.0
Air Compressor (Standby)	1		0.0	15.0%	0.0	0.0	6.5	14.5	16.0	39.0
Air Cooler (Radiator Type) Fan Motor	1		0.0	15.0%	0.0	0.0	6.5	14.5	16.0	39.0
Instrument Air Dryer	1		0.0	15.0%	0.0	0.0	3.1	20.8	16.0	39.0
Instrument Air Receiver	1	3.2	3.2	15.0%	0.5	3.7	3.1	20.8	16.0	39.0
Utility Air Receiver	1	4.0	4.0	15.0%	0.6	4.6	0.8	21.1	16.0	39.0
Black Start Air Compressor Skid	1	2.7	2.7	15.0%	0.4	3.2	7.0	19.5	16.0	39.0
66 - SEWAGE TREATMENT										
Sewage Treatment Plant	1	1.6	1.6	15.0%	0.2	1.8	22.5	18.1	16.0	39.0
Pump 5020A Motor	1		0.0	15.0%	0.0	0.0	22.5	18.1	16.0	39.0
Pump 5020B Motor (Standby Pump Motor)	1		0.0	15.0%	0.0	0.0	22.5	18.1	16.0	39.0
Bolwer 5020C Motor	1		0.0	15.0%	0.0	0.0	22.5	18.1	16.0	39.0
71- FIREWATER										
Firewater Pump Package	1	1.1	1.1	15.0%	0.2	1.3	0.0	0.0	12.5	35.5
Firewater Pump	1		0.0	15.0%	0.0	0.0	0.0	0.0	12.5	35.5
Firewater Pump Motor			0.0	15.0%	0.0	0.0	0.0	0.0	12.5	35.5
Firewater Pump Package (Standby)	1	1.1	1.1	15.0%	0.2	1.3	0.0	0.0	12.5	35.5
Firewater Pump	1		0.0	15.0%	0.0	0.0	0.0	0.0	12.5	35.5
Firewater Pump Motor			0.0	15.0%	0.0	0.0	0.0	0.0	12.5	35.5
73 - MATERIAL HANDLING										
Pedestal Crane	1	90.0	90.0	15.0%	13.5	103.5	-10.2	25.0	27.0	50.0
Hydraulic Pump Motor										
Pedestal Crane (Lighting, A/c and Misc. Loads)										
Pedestal Crane	1	90.0	90.0	15.0%	13.5	103.5	10.2	-25.0	27.0	50.0
Hydraulic Pump Motor										
Pedestal Crane (Lighting, A/c and Misc. Loads)										
76 - SAFETY EQUIPMENT										
Survival Craft	2	4.5	9.0	15.0%	1.4	10.4	29.6	11.6	21.0	44.0
Winch on the Davit has a 25 kW 2-Speed Motor			0.0	15.0%	0.0	0.0	0.0	0.0	21.0	44.0
Survival Craft	2	4.5	9.0	15.0%	1.4	10.4	-29.6	11.6	21.0	44.0
Winch on the Davit has a 25 kW 2-Speed Motor			0.0	15.0%	0.0	0.0	0.0	0.0	21.0	44.0
Rescue Craft	1	2.2	2.2	15.0%	0.3	2.5	29.6	11.6	21.0	44.0

10 MW Full Production Phase, OTEC Platform Topsides Weight Summary - Full Production Condition

TOPSIDES EQUIPMENT LIST	No of units	unit wt (mt)	Net Weight (mt)	Contingency %	Contingency (mt)	TOTAL WEIGHT (mt)	CENTER OF GRAVITY X m	Y m	Z (from MWL) m	Z (from keel) m
Winch on the Davit has a 18kW Motor			0.0	15.0%	0.0	0.0	0.0	0.0	21.0	44.0
77 - NAVIGATION AIDS										
Aids to Navigation	1	1.8	1.8	15.0%	0.3	2.1	0.0	0.0	22.0	45.0
Foghorn	1	0.5	0.5	15.0%	0.1	0.6	0.0	0.0	22.0	45.0
80 - MAIN POWER 11KV										
Turbine Generator Package	1	71.5	71.5	15.0%	10.7	82.2	-20.9	15.1	22.0	45.0
Lube Oil Skid Details	1	13.2	13.2	15.0%	2.0	15.2	-19.7	22.2	22.0	45.0
Lube Oil Auxiliary Pump Motor A	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Lube Oil Auxiliary Pump Motor B	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Inlet Guide Vane Actuator	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Lube Oil Tank Heater	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Seal Gas Heater (Optional)	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Local Control Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Generator Contol Panel / Protection Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Generator Space Heater	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Local Control Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Turbine Generator Package	1	71.5	71.5	15.0%	10.7	82.2	20.9	15.1	22.0	45.0
Lube Oil Skid Details	1	13.2	13.2	15.0%	2.0	15.2	19.7	22.2	22.0	45.0
Lube Oil Auxiliary Pump Motor A	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Lube Oil Auxiliary Pump Motor B	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Inlet Guide Vane Actuator	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Lube Oil Tank Heater	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Seal Gas Heater (Optional)	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Local Control Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Generator Contol Panel / Protection Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Generator Space Heater	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Local Control Panel	1		0.0	15.0%	0.0	0.0	-21.0	-17.6	22.0	45.0
Auxiliary Diesel Generator Package	1	59.4	59.4	15.0%	8.9	68.3	-20.8	-16.3	22.0	45.0
13.8 / 4.16 kV Transformer	1	15.2	15.2	15.0%	2.3	17.5	15.0	1.5	22.0	45.0
13.8 / 4.16 kV Transformer	1	15.2	15.2	15.0%	2.3	17.5	15.0	1.5	22.0	45.0
13.8 / .48 kV Transformer	1	5.7	5.7	15.0%	0.9	6.6	15.0	1.5	22.0	45.0
13.8 / .48 kV Transformer	1	5.7	5.7	15.0%	0.9	6.6	15.0	1.5	22.0	45.0
13.8 / 33 kV Step-up Transformer	1	41.1	41.1	15.0%	6.2	47.3	15.0	1.5	22.0	45.0
Tompsides Umbilical Termination Unit	1		0.0	15.0%	0.0	0.0	15.0	1.5	22.0	45.0
1000 HP VFD For CW and WW Pumps	1	2.0	2.0	15.0%	0.3	2.3	15.0	1.5	22.0	45.0
1000 HP VFD For CW and WW Pumps	1	2.0	2.0	15.0%	0.3	2.3	15.0	1.5	22.0	45.0
1000 HP VFD For CW and WW Pumps	1	2.0	2.0	15.0%	0.3	2.3	15.0	1.5	22.0	45.0
1000 HP VFD For CW and WW Pumps	1	2.0	2.0	15.0%	0.3	2.3	15.0	1.5	22.0	45.0
300 HP VFD For Each Ramora	1	0.6	0.6	15.0%	0.1	0.7	15.0	1.5	22.0	45.0
300 HP VFD For Each Ramora	1	0.6	0.6	15.0%	0.1	0.7	15.0	1.5	22.0	45.0
300 HP VFD For Each Ramora	1	0.6	0.6	15.0%	0.1	0.7	15.0	1.5	22.0	45.0
300 HP VFD For Each Ramora	1	0.6	0.6	15.0%	0.1	0.7	15.0	1.5	22.0	45.0
1001 HP VFD For Winch Motors	1	0.6	0.6	15.0%	0.1	0.7	15.0	1.5	22.0	45.0
1001 HP VFD For Winch Motors	1	0.6	0.6	15.0%	0.1	0.7	15.0	1.5	22.0	45.0

10 MW Full Production Phase, OTEC Platform Topsides Weight Summary - Full Production Condition

TOPSIDES EQUIPMENT LIST	No of units	unit wt (mt)	Net Weight (mt)	Contingency %	Contingency (mt)	TOTAL WEIGHT (mt)	CENTER OF GRAVITY X m	Y m	Z (from MWL) m	Z (from keel) m
84 - EMERGENCY POWER 480V										
Emergency Generator Package	1	22.6	22.6	15.0%	3.4	26.0	4.5	18.0	22.0	45.0
93 - BUILDINGS										
Living Quarters	1	107.8	107.8	15.0%	16.2	124.0	20.0	18.0	23.0	46.0
Living Quarters Electrical Lighing Loads	1	107.8	107.8	15.0%	16.2	124.0	11.9	21.0	22.0	45.0
Workshop / Warehouse	1	26.3	26.3	15.0%	3.9	30.2	11.2	21.0	22.0	45.0
Workshop / Warehouse Electrical Lighing Loads	1	26.3	26.3	15.0%	3.9	30.2	11.2	21.0	22.0	45.0
MCC/SWGR/CTRL Building	1	166.0	166.0	15.0%	24.9	190.9	18.1	0.0	17.0	40.0
MCC/SWGR/CTRL Building Electrical Lighing Loads	1		0.0	15.0%	0.0	0.0	18.1	0.0	16.0	39.0
97 - HVAC										
MCC Room AC Package	1	28.5	28.5	15.0%	4.3	32.8	15.7	-17.3	16.0	39.0
MCC Room AC Package Lightinh Loads	1	28.5	28.5	15.0%	4.3	32.8	15.7	-17.3	16.0	39.0
Helideck (Stairs,Landing & Support Frame is Exta)	1	17.3	17.3	15.0%	2.6	19.9	15.7	-17.3	16.0	39.0
22 - Ammonia Tank Storage										
NH3 Tanks (tanks & full fluid capacity)	1	62.0	62.0	15.0%	9.3	71.3	-12.9	0.0	16.0	39.0
NH3 Tanks (tanks & full fluid capacity)	1	62.0	62.0	15.0%	9.3	71.3	-16.0	0.0	16.0	39.0
NH3 Tanks (tanks & full fluid capacity)	1	62.0	62.0	15.0%	9.3	71.3	-19.2	0.0	16.0	39.0
NH3 Tanks (tanks & full fluid capacity)	1	62.0	62.0	15.0%	9.3	71.3	-22.3	0.0	16.0	39.0
Total Topside Utilities and Power Equipment			**1480.1**	**14.7%**	**217.6**	**1,697.7**	**4.3**	**3.6**	**20.4**	**43.4**
Topside Bulk/Piping Weight	-	-	339.5	0.0%	0.0	339.5	4.3	3.6	20.4	43.4
Topsides Structure (to be verified)										
Deck Structure	-	-	1820.0	15.0%	273.0	2093.0	0.0	0.0	17.0	40.0
Remoras Support - west	-	-	20.0	15.0%	3.0	23.0	-25.0	0.0	16.0	39.0
Remoras Support - east	-	-	20.0	15.0%	3.0	23.0	25.0	0.0	16.0	39.0
Helideck	-	-	22.0	15.0%	3.3	25.3	28.2	28.2	29.0	52.0
Total Topsides Structure			**1882.0**	**15.0%**	**282.3**	**2,164.3**	**0.3**	**0.3**	**17.1**	**40.1**
Total Topsides Weight			**3855**	**14.0%**	**538**	**4,526.0**	**2.1**	**1.8**	**19.1**	**42.1**

Note: 1. Top and bottom CWP guide weights are part of hull and will be included in hull weights.

Top Guide	-	rem	13.1	25.0%	3.3	16.4	0.00	0.00	-3.5	19.5
Top Guide Pads	-	remove	20.0	30.0%	6.0	26.0	0.00	0.00	-3.5	19.5
Bottom Guide	-	rem	24.0	25.0%	6.0	30.0	0.00	0.00	-33.0	-10.0
Bottom Guide Extension	-	rem	100.0	30.0%	30.0	130.0	0.00	0.00	-31.0	-8.0

2. Draft = 23.0 m

3. Elevations (from MWL)

Top Of the Column = 11.5 m
Top of the Lower Deck = 15.0 m
Top of the Upper Deck = 21.0 m

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-4
Platform Piping and Instrument Diagrams
OTEC-2010-001

17 September 2010

Prepared for:

Naval Facilities Engineering Command
Naval Facilities Engineering Service Center (NFESC)
1100 23rd Avenue
Port Hueneme, CA 93043-4370
Attn: Mr. Brian Cable, Contracting Officer Representative

Prepared by:

Lockheed Martin MS2
9500 Godwin Drive
Manassas, VA 20110

Distribution Statement A: Approved for public release; distribution is unlimited

OTEC- PIPING & INSTRUMENTATION DIAGRAM DRAWING INDEX

REVISIONS		DRAWING	TITLE
CURRENT	DATE		
A	16JUL10	H09117A-T-DWG-MS-30000	DRAWING INDEX
A	16JUL10	H09117A-T-DWG-MS-31220	PIPING & INSTRUMENT DIAGRAM-AMMONIA STORAGE TANKS
A	16JUL10	H09117A-T-DWG-MS-31221	PIPING & INSTRUMENT DIAGRAM-AMMONIA STORAGE TANKS
A	16JUL10	H09117A-T-DWG-MS-31440	PIPING & INSTRUMENT DIAGRAM-OILY WATER TREATMENT SYSTEM
A	16JUL10	H09117A-T-DWG-MS-31470	PIPING & INSTRUMENT DIAGRAM-CHEMICAL INJECTION SYSTEM
A	16JUL10	H09117A-T-DWG-MS-31500	PIPING & INSTRUMENT DIAGRAM-SEAWATER LIFT PUMPS
A	16JUL10	H09117A-T-DWG-MS-31530	PIPING & INSTRUMENT DIAGRAM-FRESH WATER MAKER
A	16JUL10	H09117A-T-DWG-MS-31531	PIPING & INSTRUMENT DIAGRAM-FRESH WATER STORAGE TANKS
A	16JUL10	H09117A-T-DWG-MS-31532	PIPING & INSTRUMENT DIAGRAM-POTABLE WATER PRESSURE SET
A	16JUL10	H09117A-T-DWG-MS-31533	PIPING & INSTRUMENT DIAGRAM-HP WASHDOWN SKID
A	16JUL10	H09117A-T-DWG-MS-31560	PIPING & INSTRUMENT DIAGRAM-OPEN DRAIN SYSTEM
A	16JUL10	H09117A-T-DWG-MS-31620	PIPING & INSTRUMENT DIAGRAM-DIESEL FUEL SYSTEM
A	16JUL10	H09117A-T-DWG-MS-31630	PIPING & INSTRUMENT DIAGRAM-AIR COMPRESSOR SKID
A	16JUL10	H09117A-T-DWG-MS-31631	PIPING & INSTRUMENT DIAGRAM-AIR COMPRESSOR SKID
A	16JUL10	H09117A-T-DWG-MS-31632	PIPING & INSTRUMENT DIAGRAM-AIR COMPRESSOR SKID
A	16JUL10	H09117A-T-DWG-MS-31633	PIPING & INSTRUMENT DIAGRAM-INSTRUMENT AIR RECEIVER
A	16JUL10	H09117A-T-DWG-MS-31660	PIPING & INSTRUMENT DIAGRAM-SEWAGE TREATMENT UNIT
A	16JUL10	H09117A-T-DWG-MS-31710	PIPING & INSTRUMENT DIAGRAM-FIREWATER PUMP A
A	16JUL10	H09117A-T-DWG-MS-31711	PIPING & INSTRUMENT DIAGRAM-FIREWATER PUMP B
A	16JUL10	H09117A-T-DWG-MS-31712	PIPING & INSTRUMENT DIAGRAM-FIREWATER DISTRIBUTION
A	16JUL10	H09117A-T-DWG-MS-31800	PIPING & INSTRUMENT DIAGRAM-TURBINE GENERATOR A
A	16JUL10	H09117A-T-DWG-MS-31801	PIPING & INSTRUMENT DIAGRAM-TURBINE GENERATOR B
A	16JUL10	H09117A-T-DWG-MS-31804	PIPING & INSTRUMENT DIAGRAM-AUXILIARY DIESEL GENERATOR
A	16JUL10	H09117A-T-DWG-MS-31830	PIPING & INSTRUMENT DIAGRAM-EMERGENCY GENERATOR

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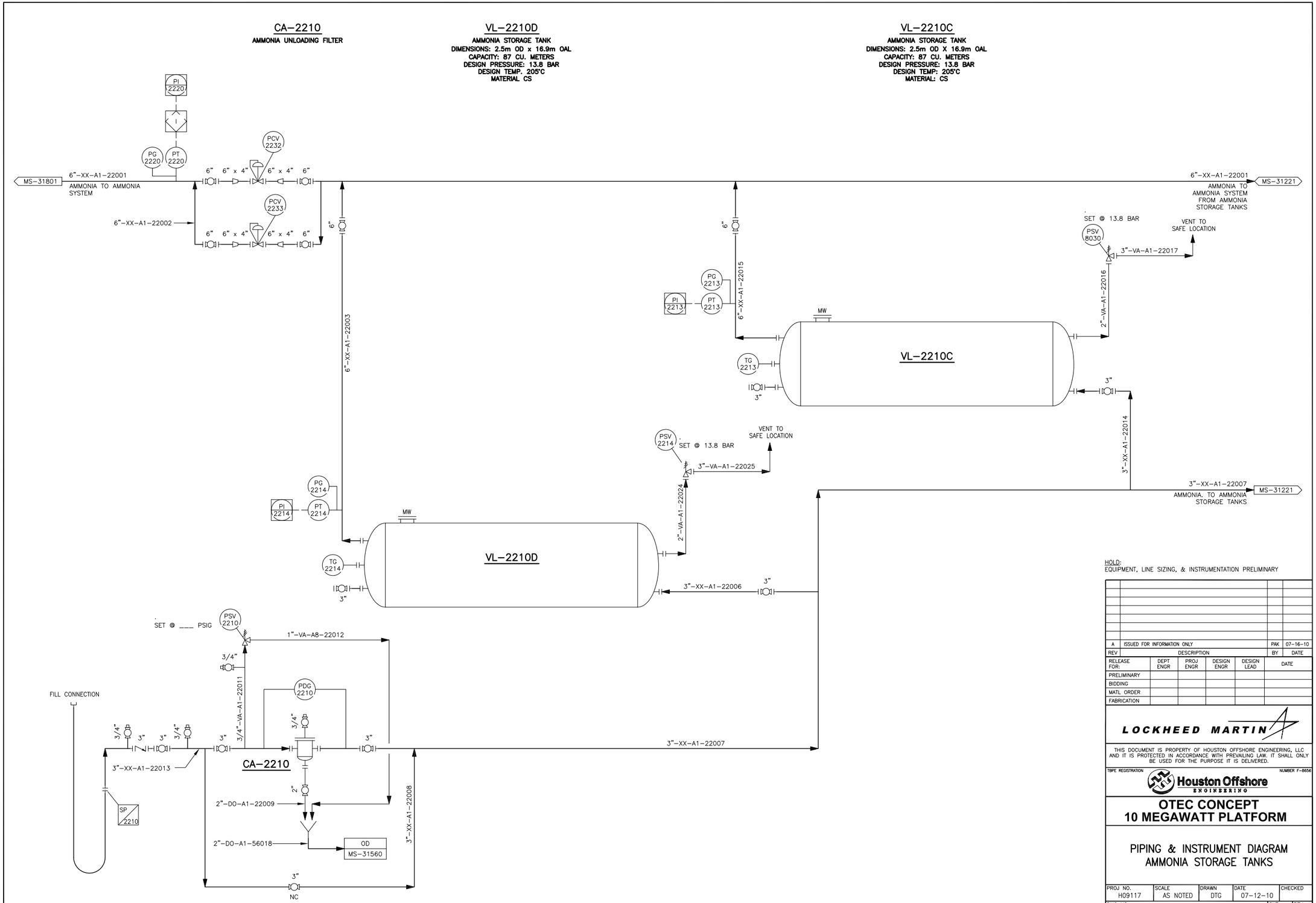
OTEC CONCEPT
10 MEGAWATT PLATFORM

DRAWING INDEX

PROJ NO.	SCALE	DRAWN	DATE	CHECKED
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DWG NO.	SHT	REV
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OTEC CONCEPT 10 MEGAWATT PLATFORM

PIPING & INSTRUMENT DIAGRAM AMMONIA STORAGE TANKS

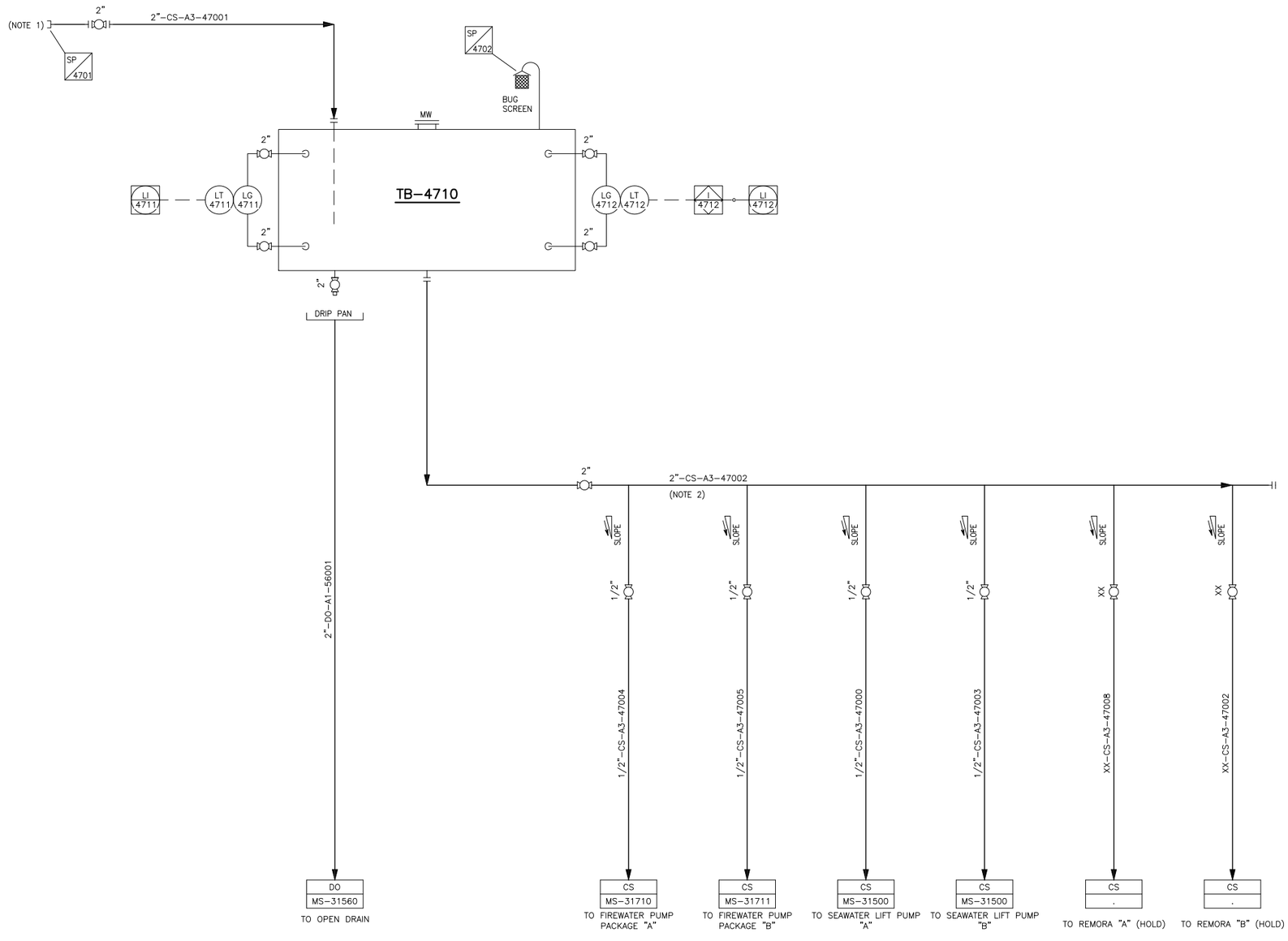
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DWG NO.	SHT	REV
H09117-T-DWG-MS-31220	01	A

A1 - 594 x 841

TB-4710

SODIUM HYPOCHLORITE TANK
SIZE: (HOLD)
CAPACITY: (HOLD)
MATERIAL: STAINLESS STEEL



NOTES:

1. QUICK CONECT TO BE LOCATED AT ELEVATION ABOVE TANK FOR CHEMICAL TO BE LOADED.

2. GRAVITY FEED TO FIREWATER PUMPS AND SEAWATER LIFT PUMPS.

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OTEC CONCEPT 10 MEGAWATT PLATFORM

PIPING & INSTRUMENT DIAGRAM CHEMICAL INJECTION SYSTEM

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DWG NO.	SHT	REV
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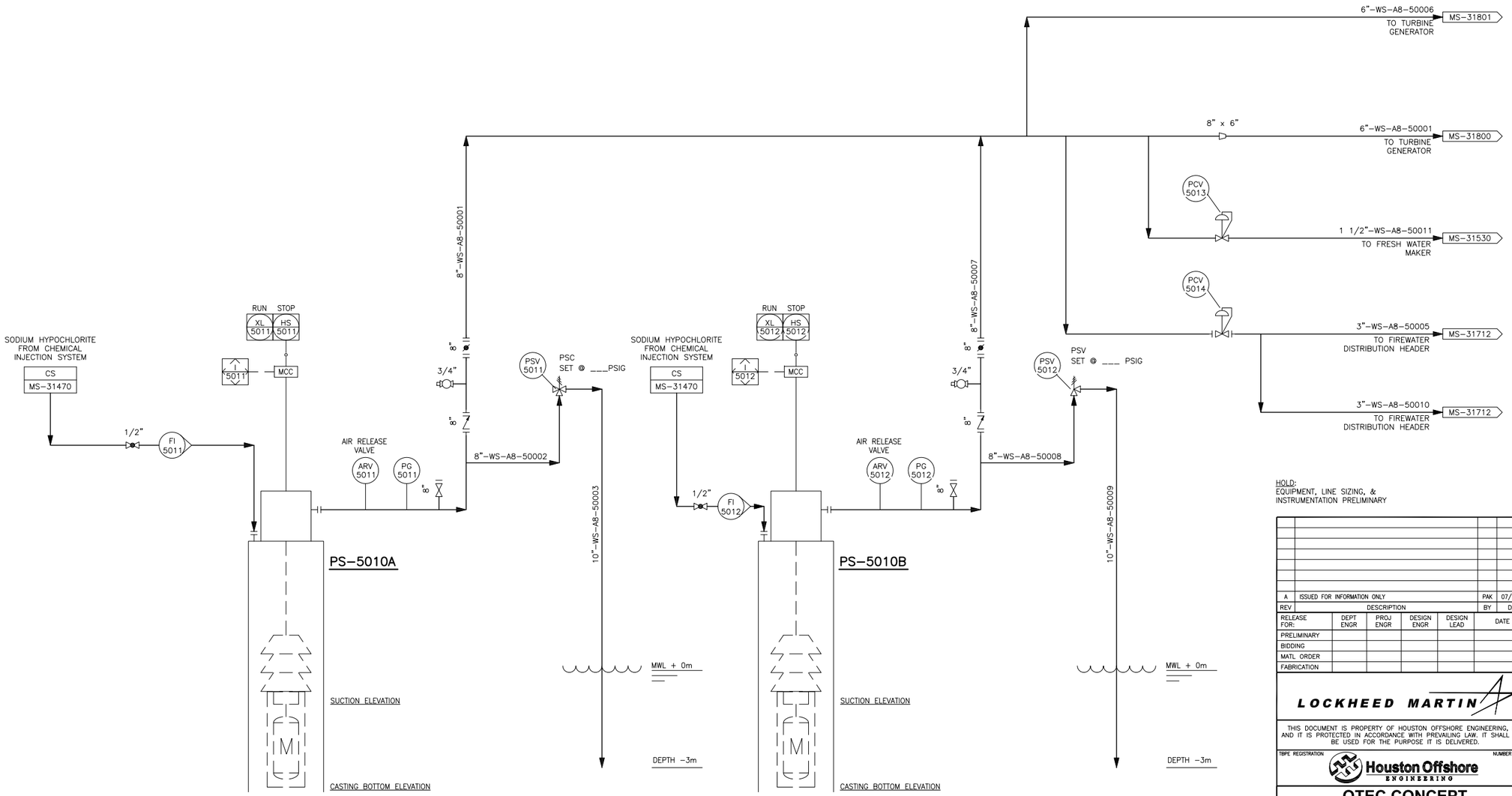
A1 - 594 x 841

PS–5010A

SEAWATER LIFT PUMP
CAPACITY: 400 CU. METERS/HR
TDH: 90m

PS–5010B

SEAWATER LIFT PUMP
CAPACITY: 400 CU. METERS/HR
TDH: 90m



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OTEC CONCEPT
10 MEGAWATT PLATFORM

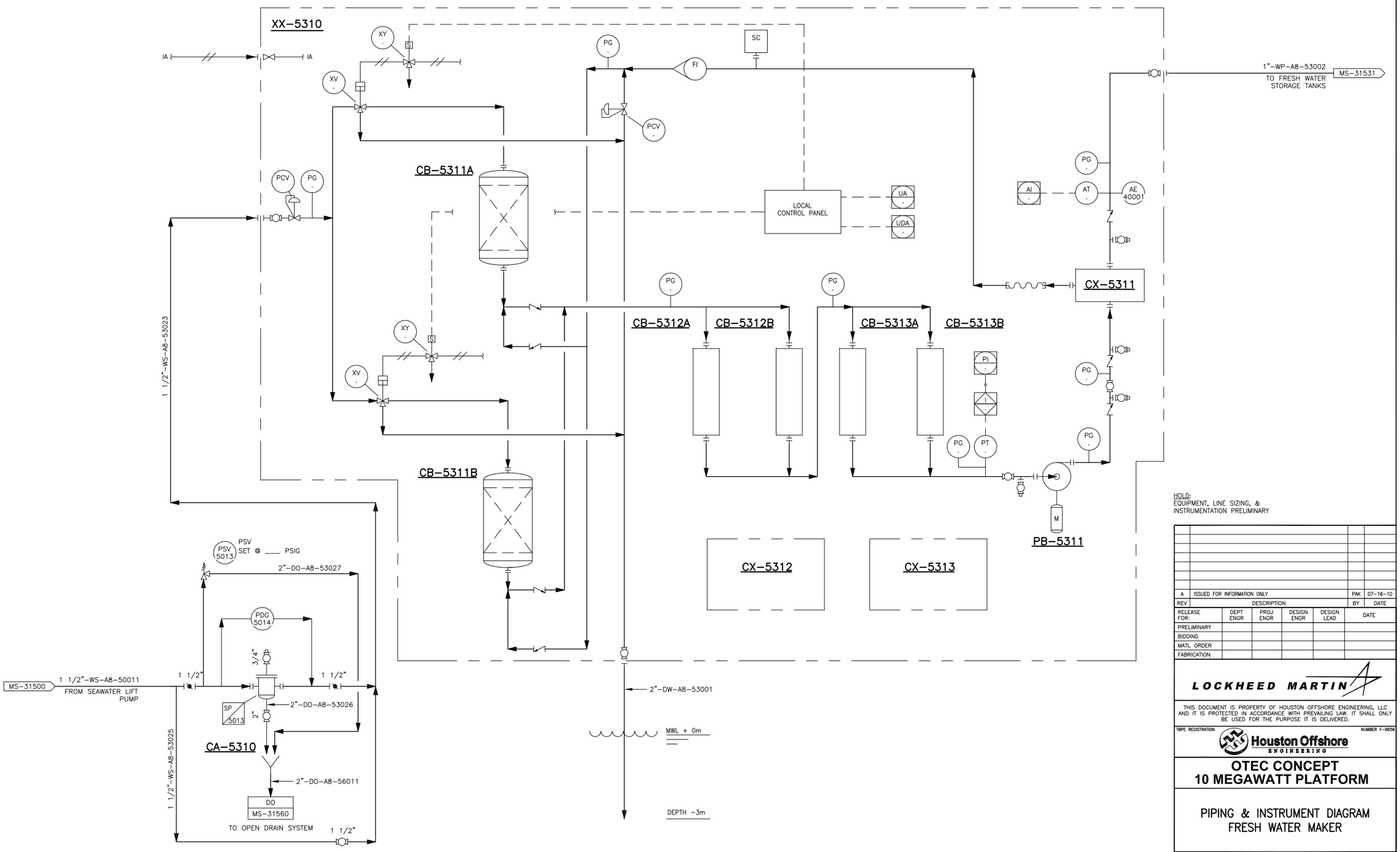
PIPING & INSTRUMENT DIAGRAM
SEAWATER LIFT PUMPS

PROJ NO.	SCALE	DRAWN	DATE	CHECKED
H09117	AS NOTED	DTG	07–07–10	

DWG NO.	SHT	REV
H09117–T–DWG–MS–31500	01	A

A1 – 594 x 841

XX-5310	CA-5310	CB-5311A	CB-5311B	CB-5312A	CB-5312B	CX-5312	CX-5313	CB-5313A	CB-5313B	PB-5311	CX-5311
FRESH WATER MAKER CAPACITY: 15 CU. METERS/DAY POWER: 22KW	SEAWATER STRAINER	MEDIA FILTER	MEDIA FILTER	COARSE FILTER	COARSE FILTER	CHEMICAL CONDITIONING UNIT	FRESH WATER HARDENING UNIT	FINE FILTER	FINE FILTER	FRESH WATER MAKER PUMP	RO MEMBRANE



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OTEC CONCEPT
10 MEGAWATT PLATFORM

PIPING & INSTRUMENT DIAGRAM
FRESH WATER MAKER

PROJ NO.	SCALE	DRAWN	DATE	CHECKED
H09117	AS NOTED	DTG	06-28-10	

DWG NO.	SHT	REV
H09117-T-DWG-MS-31530	01	A

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CA-5301

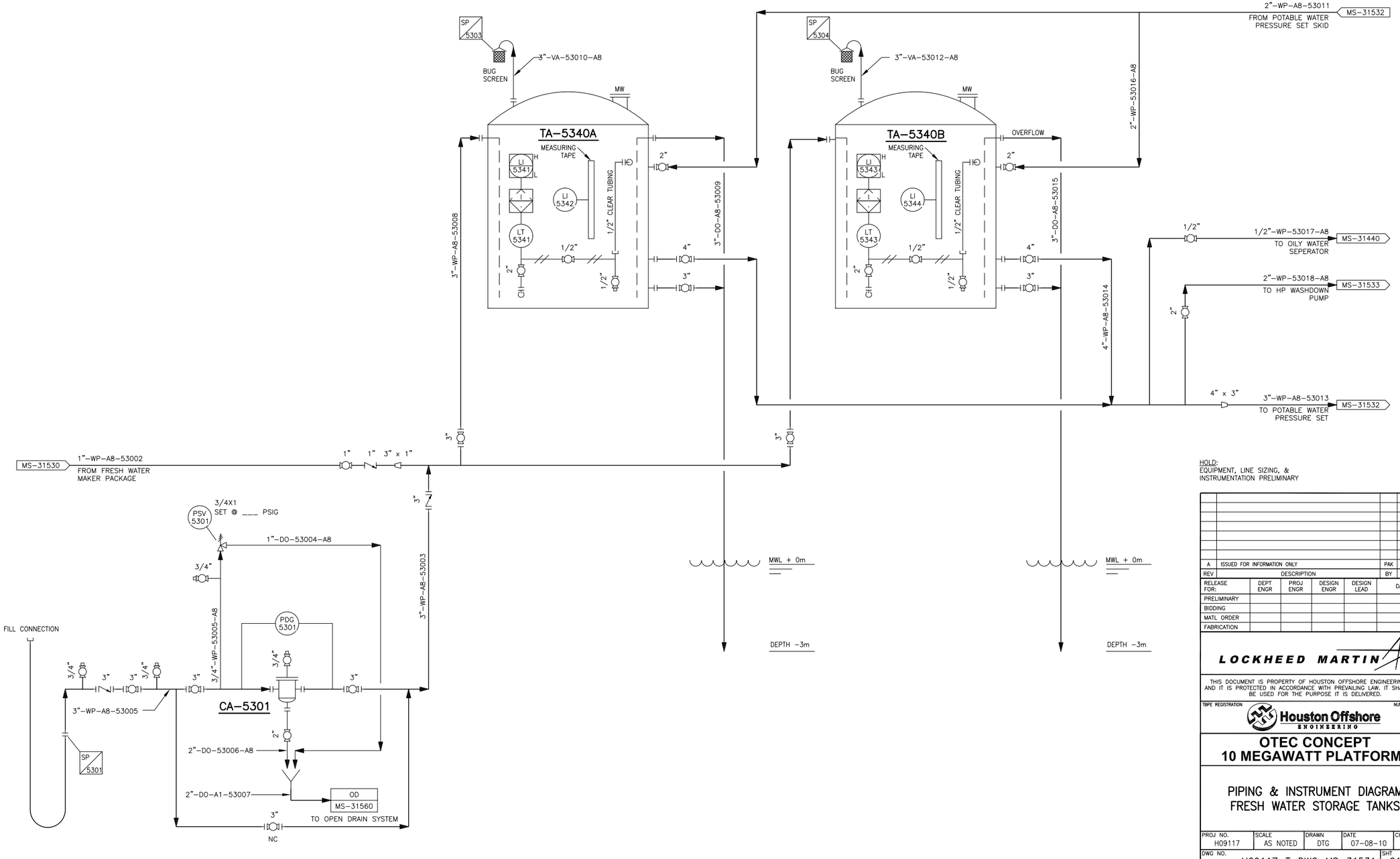
FRESH WATER UNLOADING FILTER
DESIGN PRESS: (HOLD)
DESIGN TEMP: (HOLD)
MATERIAL: (HOLD)

TA-5340A

FRESH WATER STORAGE TANK
SIZE:-3.2M OAH
CAPACITY: 19.3m³
DESIGN PRESS: ATM
DESIGN TEMP: AMB
MATERIAL: PE

TA-5340B

FRESH WATER STORAGE TANK
SIZE:-3.2M OAH
CAPACITY: 19.3m³
DESIGN PRESS: ATM
DESIGN TEMP: AMB
MATERIAL: PE



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OTEC CONCEPT
10 MEGAWATT PLATFORM

PIPING & INSTRUMENT DIAGRAM
FRESH WATER STORAGE TANKS

PROJ NO.	SCALE	DRAWN	DATE	CHECKED
H09117	AS NOTED	DTG	07-08-10	

DWG NO.	SHT	REV
H09117-T-DWG-MS-31531	01	A

A1 - 594 x 841

XE–5330
POTABLE WATER PRESSURE SET

PA–5330A
POTABLE WATER PRESSURE SET PUMP
CAPACITY: 35 GPM
DIFF HEAD: 100 PSI
HORSEPOWER:

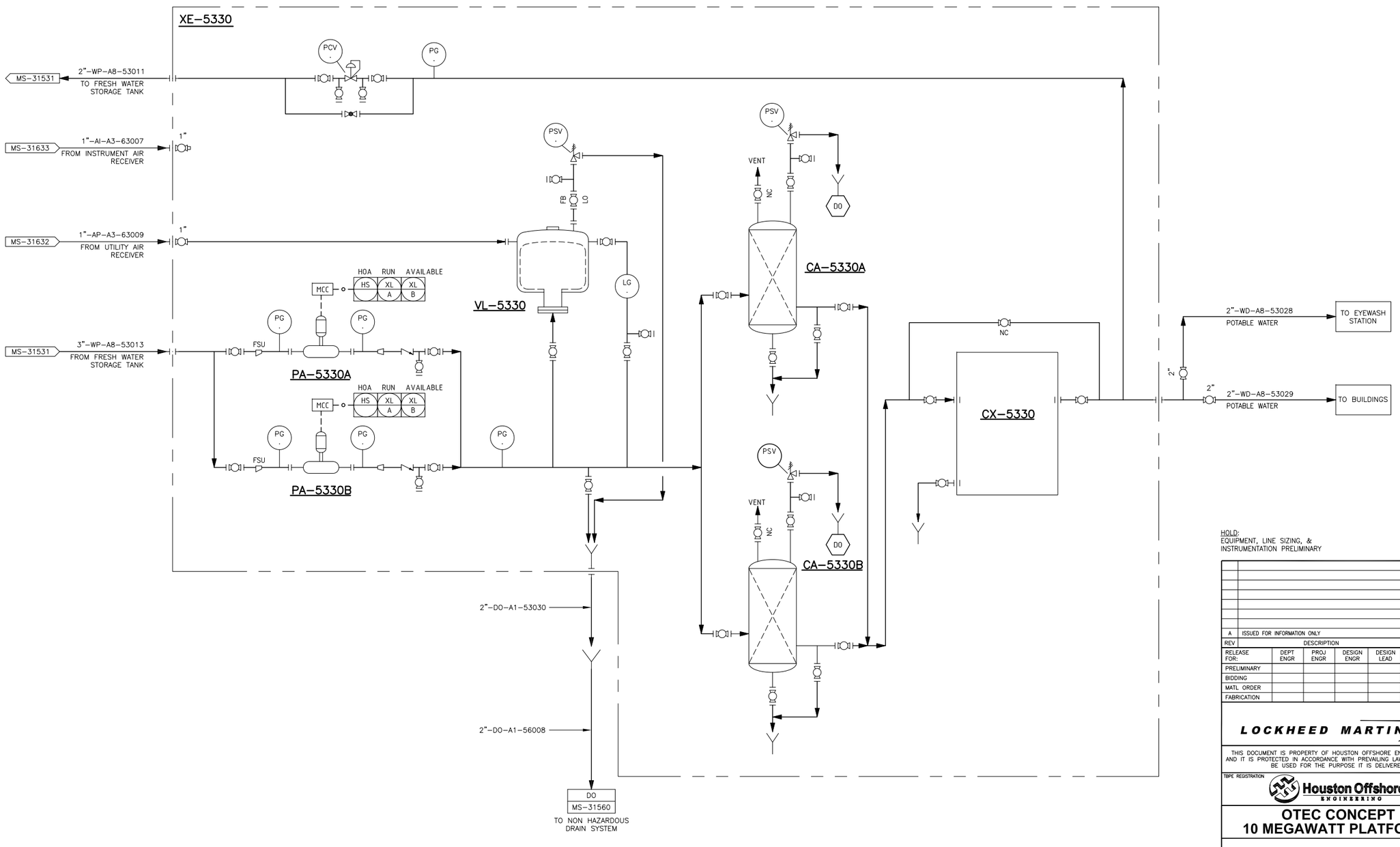
PA–5330B
POTABLE WATER PRESSURE SET PUMP
CAPACITY: 35 GPM
DIFF HEAD: 100 PSI
HORSEPOWER:

VL–5330
POTABLE WATER PRESSURE TANK

CA–5330A
POTABLE WATER CHARCOAL FILTER

CA–5330B
POTABLE WATER CHARCOAL FILTER

CX–5330
UV STERILIZER



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OTEC CONCEPT 10 MEGAWATT PLATFORM

PIPING & INSTRUMENT DIAGRAM POTABLE WATER PRESSURE SET

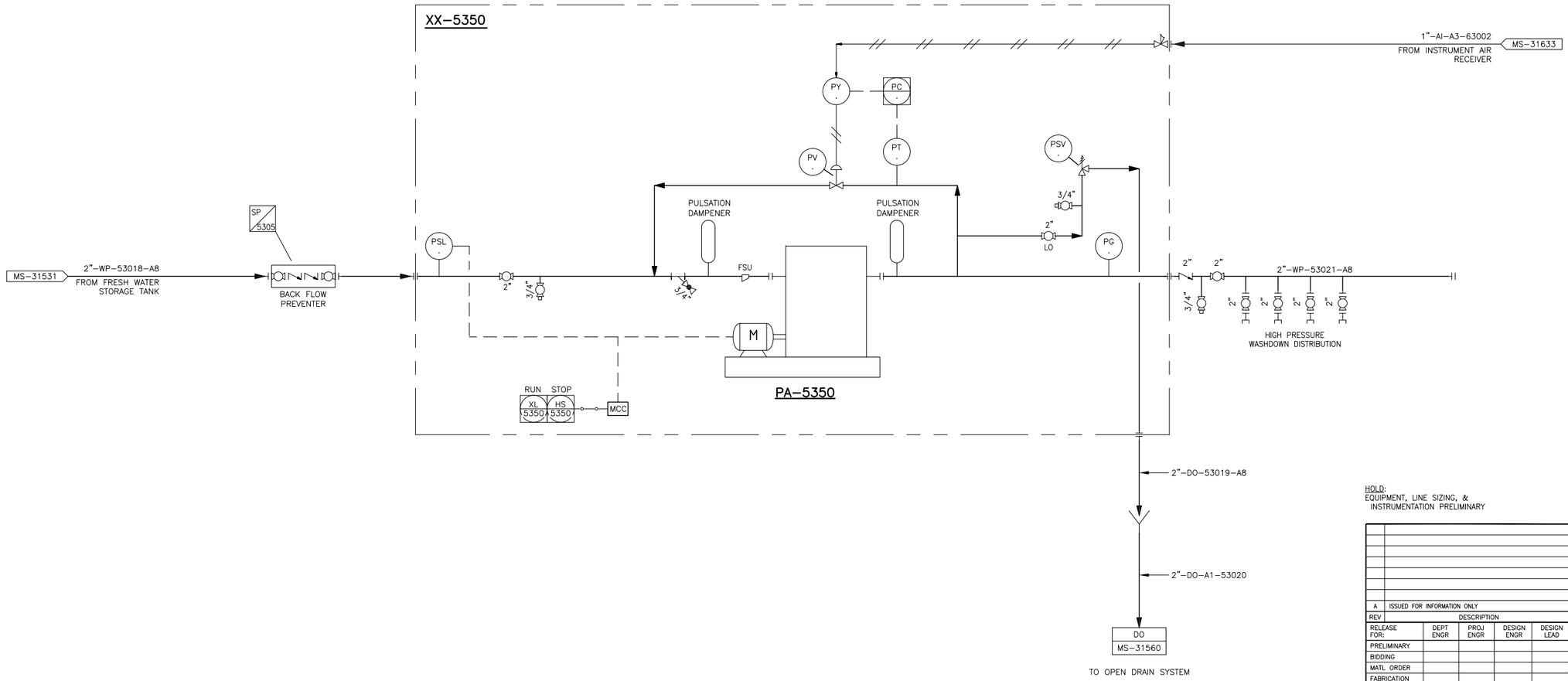
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DWG NO.	SHT	REV
H09117–T–DWG–MS–31532	01	A

A1 – 594 x 841

XX–5350
WASHDOWN WATER SKID
PRESSURE: 240 BARG
CAPACITY: 0.68m3/HR

PA–5350
WASHDOWN WATER PUMP
DIFF HEAD: 2448M
CAPACITY: 0.68 CU. METERS/HR



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OTEC CONCEPT
10 MEGAWATT PLATFORM

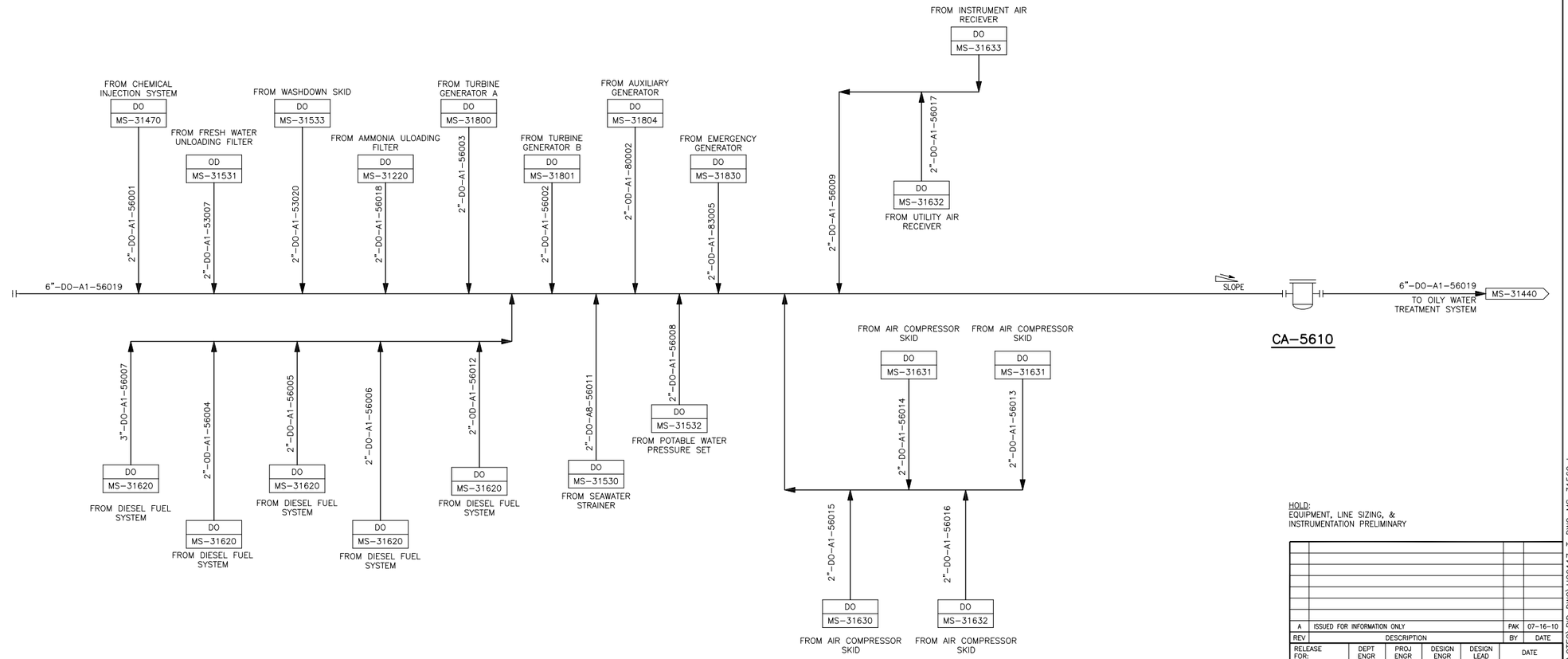
PIPING & INSTRUMENT DIAGRAM
HP WASHDOWN SKID

PROJ NO.	SCALE	DRAWN	DATE	CHECKED
H09117	AS NOTED	DTG	07–08–10	

DWG NO.	SHT	REV
H09117–T–DWG–MS–31533	01	A

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CA–5610
OPEN DRAIN FILTER



CA–5610

CA–5610

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Houston Offshore ENGINEERING

OTEC CONCEPT 10 MEGAWATT PLATFORM

PIPING & INSTRUMENT DIAGRAM OPEN DRAIN SYSTEM

PROJ NO.	SCALE	DRAWN	DATE	CHECKED
H09117	AS NOTED	DTG	06–30–10	

DWG NO.	SHT	REV
H09117–T–DWG–MS–31560	01	A

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X:\Halkyard\H09117 NAFAC–OTEC Platform Pre–FEED\Marine Systems\PID\OTEC\PID DWG\H09117–T–DWG–MS–31560.dwg

TA-6220
DIESEL STORAGE TANK
SIZE: 2.7M.O.D. X 9.1M HT
CAPACITY: 37 CU. METERS

MA-7310B
PEDISTAL CRANE

XX-6210
DIESEL TRANSFER SKID
CAPACITY: 10 CU. METERS/HR

CA-6210
DIESEL FUEL FILTER

PE-6210A
DIESEL FUEL TRANSFER PUMP

PE-6210B
DIESEL FUEL TRANSFER PUMP

VJ-6210
DIESEL FUEL COALESCER

MA-7310B

SP 6210
BUG SCREEN
ACCESS HOLE
GRATING FLOOR
3"-DO-A1-62013
3"-DO-A1-56007
OD MS-31560
TO OPEN DRAIN SYSTEM
6"-VA-A1-62012
2"-OD-A1-62010
2"-DO-A1-56006
OD MS-31560
TO OPEN DRAIN SYSTEM
LT 6222
LG 6222
MAG
LI 6222
TA-6220
LG 6221
LT 6221
LI 6221
DOWNCOMER PIPE
18" MW
LG 6223
2"-DO-A1-62002
2"-DO-A1-56005
DO MS-31560
TO OPEN DRAIN SYSTEM
3"-OF-A1-62007
3"-OF-A1-62008
2"-OD-A1-56004
DO MS-31560
TO OPEN DRAIN SYSTEM

PCV 6210
PG 6210
2"-OF-A1-62011-A1
2"-OF-A1-62003

XX-6210

SET AT ___ PSIG
PSV
PDG
LO
VJ-6210
2"-OF-A1-62001
TO AUXILIARY DIESEL GENERATOR
MS-31804
2"-OF-A1-62004
TO EMERGENCY GENERATOR
MS-31830
2"-DO-A1-62009
2"-OD-A1-56012
DO MS-31560
TO OPEN DRAIN SYSTEM
2" NC

SDV
PG
RUN STOP
HS HS
MCC
M
PE-6210A
PE-6210B

1 1/2E2
SET AT
150 PSIG
PSV
PDG
CA-6210
FILL CONNECTION
SP 6211
3"-OF-A1-62006
NC

HOLD:
EQUIPMENT, LINE SIZING, &
INSTRUMENTATION PRELIMINARY

REV	DESCRIPTION	BY	DATE
A	ISSUED FOR INFORMATION ONLY	PAK	07-16-10

RELEASE FOR:	DEPT ENGR	PROJ ENGR	DESIGN ENGR	DESIGN LEAD	DATE
PRELIMINARY					
BIDDING					
MATL ORDER					
FABRICATION					

LOCKHEED MARTIN

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TBPE REGISTRATION NUMBER F-8656
Houston Offshore ENGINEERING

OTEC CONCEPT
10 MEGAWATT PLATFORM

PIPING & INSTRUMENT DIAGRAM
DIESEL FUEL SYSTEM

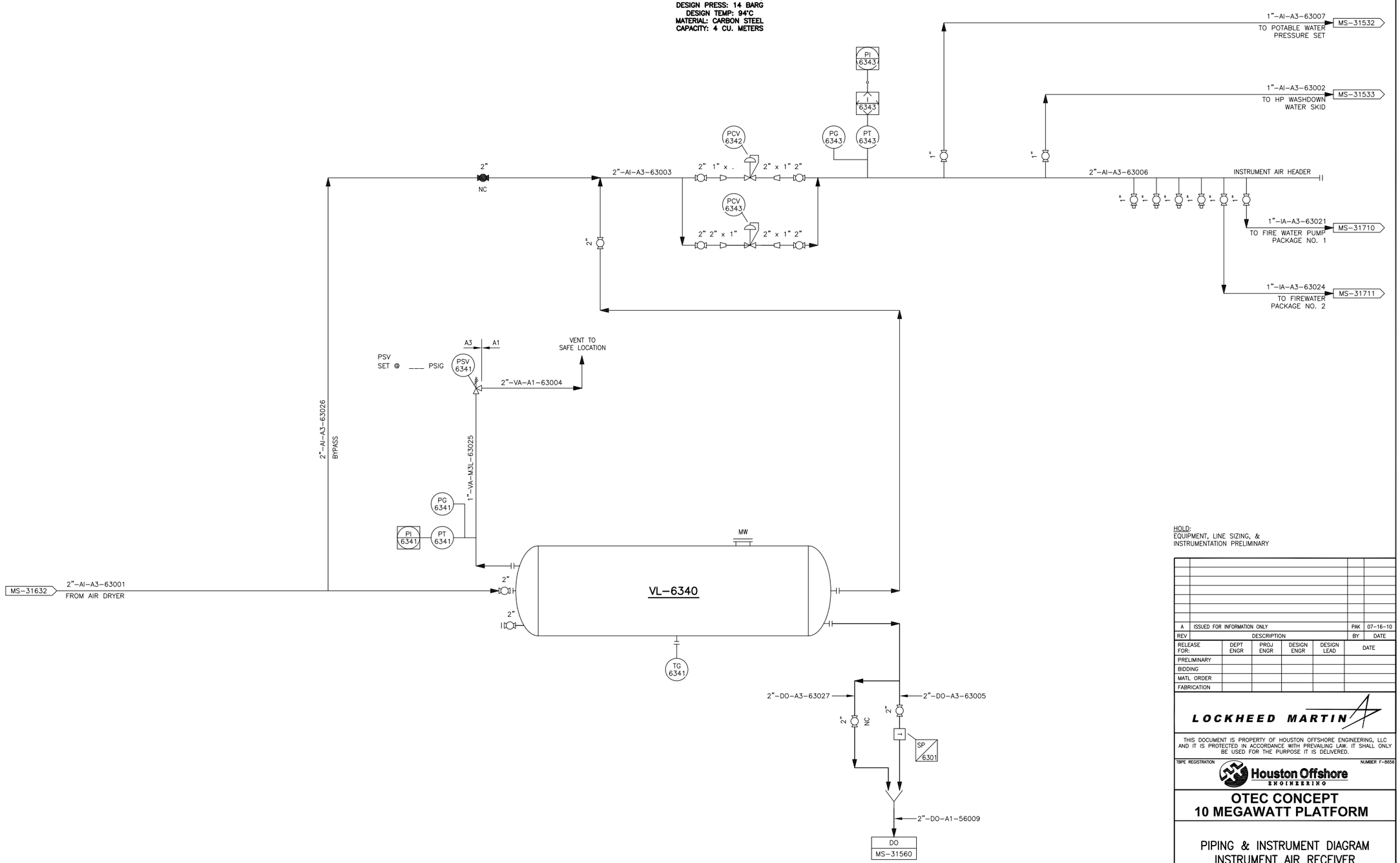
PROJ NO.	SCALE	DRAWN	DATE	CHECKED
H09117	AS NOTED	DTG	07-13-10	

DWG NO.	SHT	REV
H09117-T-DWG-MS-31620	01	A

A1 - 594 x 841

VL-6340

INSTRUMENT AIR RECIEVER
SIZE: 1.2m OD X 3.6m S/S
DESIGN PRESS: 14 BARG
DESIGN TEMP: 94°C
MATERIAL: CARBON STEEL
CAPACITY: 4 CU. METERS



HOLD:
EQUIPMENT, LINE SIZING, &
INSTRUMENTATION PRELIMINARY

REV	DESCRIPTION	BY	DATE
A	ISSUED FOR INFORMATION ONLY	PAK	07-16-10

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PRELIMINARY					
BIDDING					
MATL ORDER					
FABRICATION					

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Houston Offshore ENGINEERING

OTEC CONCEPT 10 MEGAWATT PLATFORM

PIPING & INSTRUMENT DIAGRAM INSTRUMENT AIR RECEIVER

PROJ NO.	SCALE	DRAWN	DATE	CHECKED
H09117	AS NOTED	DTG	07-06-10	

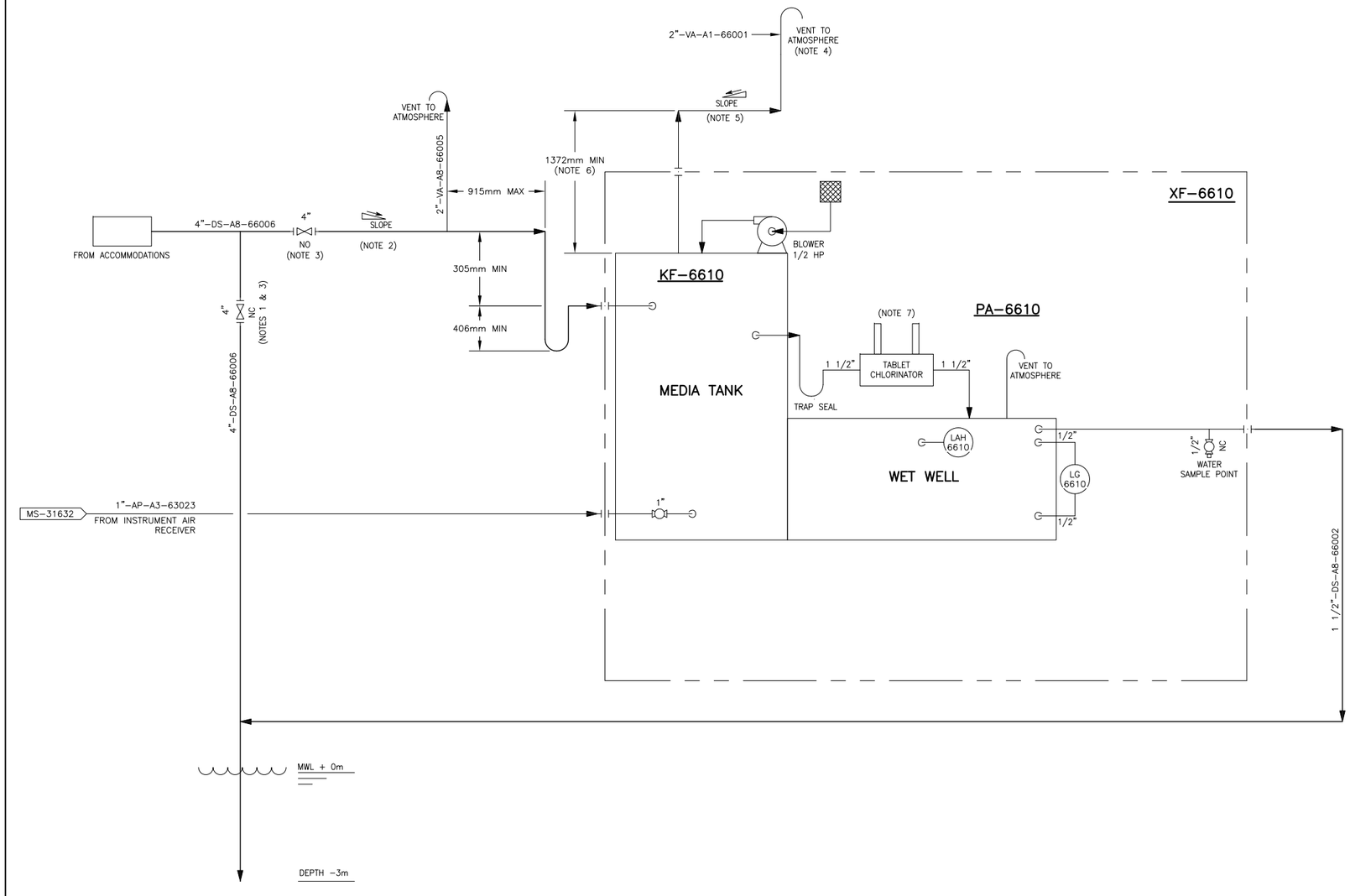
DWG NO.	SHT	REV
H09117-T-DWG-MS-31633	01	A

A1 - 594 x 841

KF–6610
SEWAGE TREATMENT BLOWER

XF–6610
SEWAGE TREATMENT UNIT CAPACITY: 1.14m^3

PA–6610
SEWAGE TREATMENT DISCHARGE PUMP



NOTES:

1. EMERGENCY BYPASS DISCHARGE REQUIRED TO PROVIDE USE OF SANITARY FACILITIES IN INSTANCE OF EQUIPMENT MALFUNCTION.

2. GRAVITY SOIL PIPING LEADING TO MEDIA TANK TO SLOPE NOT LESS THAN 21mm PER METER OF PIPING

3. MOUNT SEWAGE INLET AND EMERGENCY BYPASS VALVES WITH STEMS IN THE UPRIGHT VERTICAL POSITION.

4. DO NOT COMBINE MEDIA TANK VENT WITH ANY OTHER VENT. VENT TO TERMINATE 3M FROM ANY SOURCE OF IGNITION AND ANY VENTILATION AIR VENT.

5. HORIZONTAL OFFSETS IN MEDIA TANK VENT MUST BE SLOPED NOT LESS THAN 42mm PER METER OF PIPING.

6. ALLOW AT LEAST 1,372mm CLEARANCE ABOVE MEDIA TANK COVER TO VENT SPOOL FLANGE CONNECTION TO PERMIT REMOVAL OF COVER FOR INTERNAL REPAIR.

7. ALLOW AT LEAST 305mm CLEARANCE ABOVE CHLORINE TABLET REFILL TUBES FOR TUBE REMOVAL.

HOLD:
EQUIPMENT, LINE SIZING, & INSTRUMENTATION PRELIMINARY

REV	DESCRIPTION	BY	DATE
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BIDDING					
MATL ORDER					
FABRICATION					

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Houston Offshore ENGINEERING

OTEC CONCEPT 10 MEGAWATT PLATFORM

PIPING & INSTRUMENT DIAGRAM SEWAGE TREATMENT PACKAGE

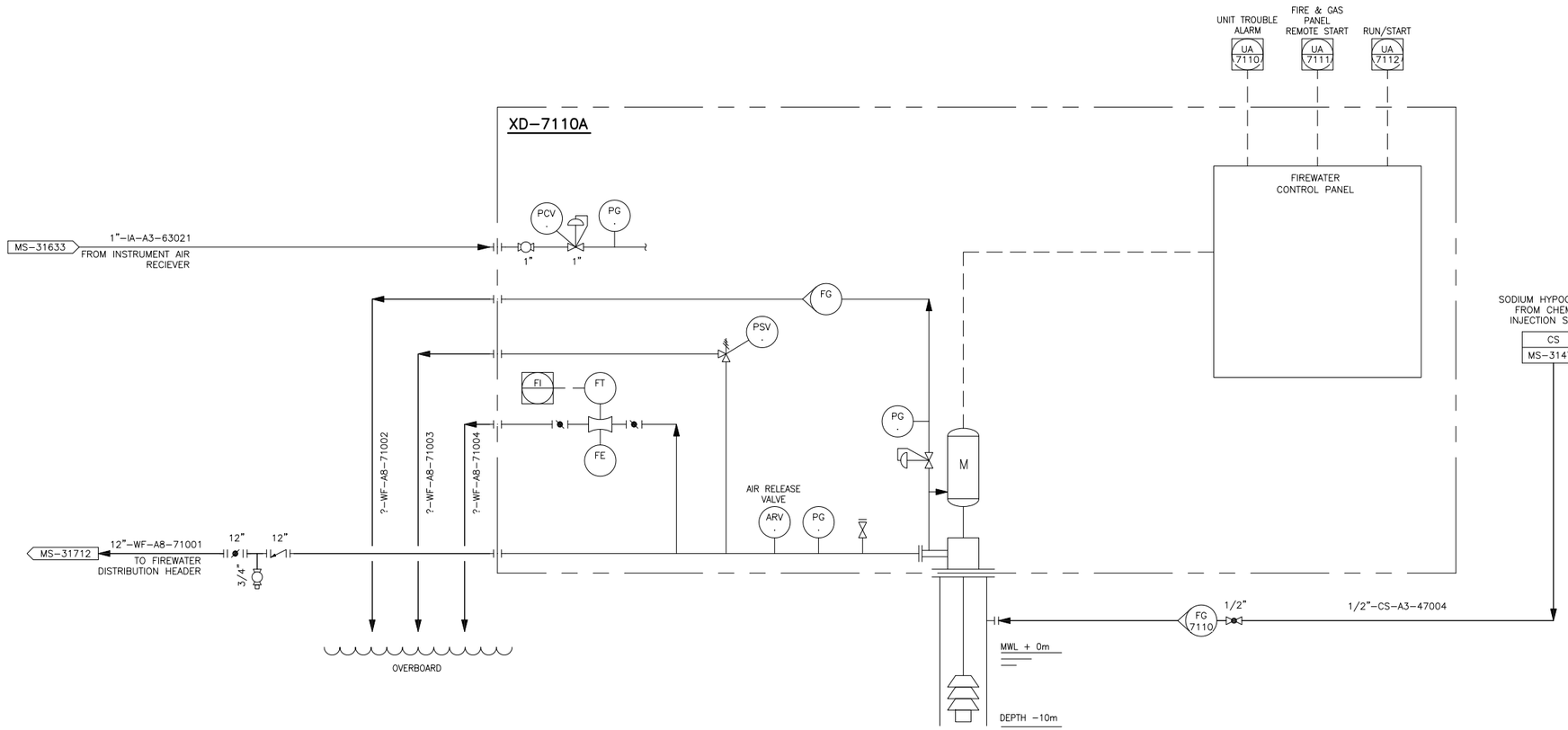
PROJ NO.	SCALE	DRAWN	DATE	CHECKED
H09117	AS NOTED	DTG	07–12–10	

DWG NO.	SHT	REV
H09117–T–DWG–MS–31660	01	A

A1 – 594 x 841

XD–7110A

FIREWATER PUMP
CAPACITY: 114 CU. METERS/HR
HEAD: 8.9M



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EQUIPMENT, LINE SIZING, & INSTRUMENTATION PRELIMINARY

REV	DESCRIPTION	BY	DATE
A	ISSUED FOR INFORMATION ONLY	PAK	07–16–10

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PRELIMINARY					
BIDDING					
MATL ORDER					
FABRICATION					

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Houston Offshore ENGINEERING

OTEC CONCEPT 10 MEGAWATT PLATFORM

PIPING & INSTRUMENT DIAGRAM
FIREWATER PUMP A

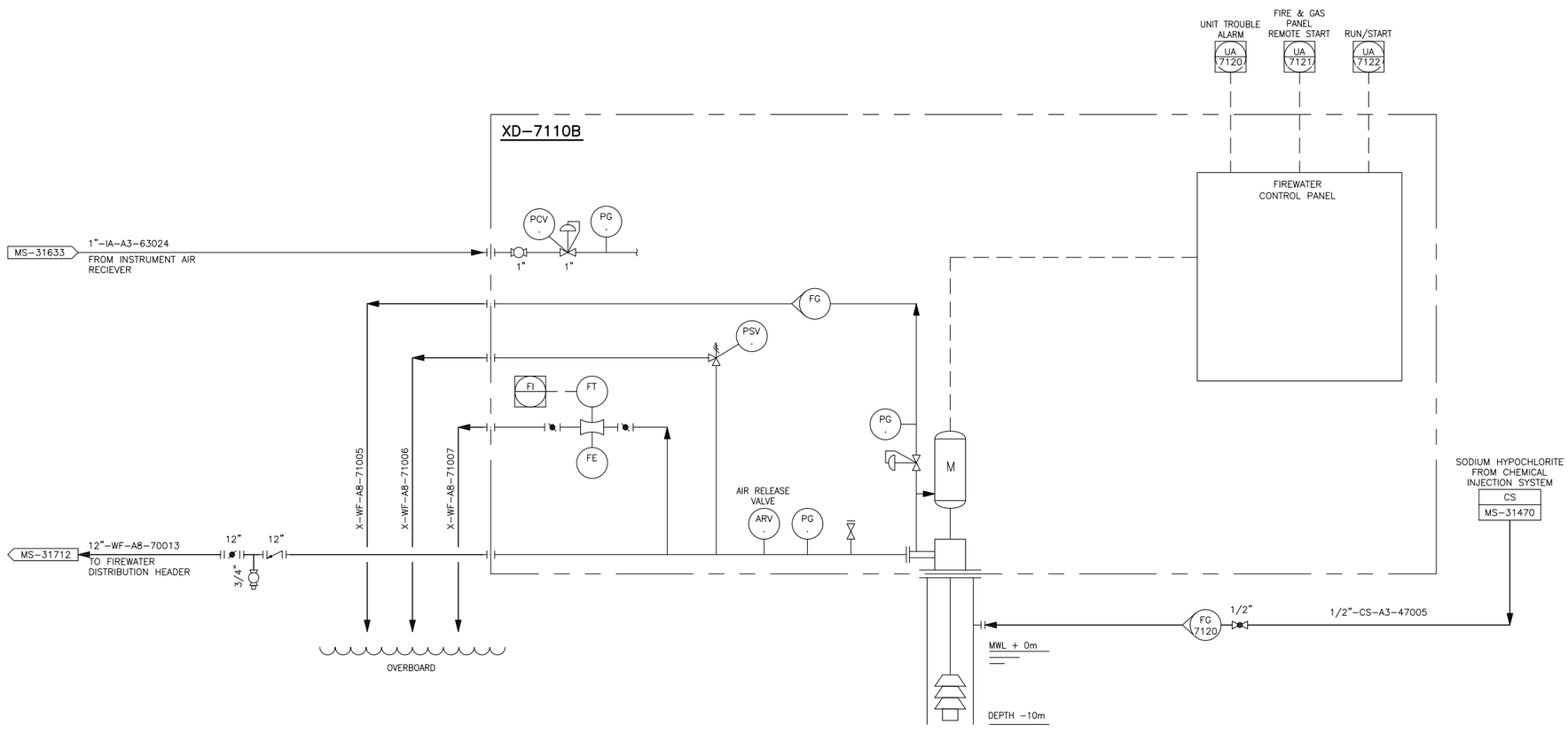
PROJ NO.	SCALE	DRAWN	DATE	CHECKED
H09117	AS NOTED	DTG	07–14–10	

DWG NO.	SHT	REV
H09117–T–DWG–MS–31710	01	A

A1 – 594 x 841

XD–7110B

FIREWATER PUMP
CAPACITY: 114 CU. METERS/HR
HEAD: 8.9M



HOLD:
EQUIPMENT, LINE SIZING, &
INSTRUMENTATION PRELIMINARY

REV	DESCRIPTION	BY	DATE
A	ISSUED FOR INFORMATION ONLY	PAK	07–16–10

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BIDDING					
MATL ORDER					
FABRICATION					

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Houston Offshore ENGINEERING

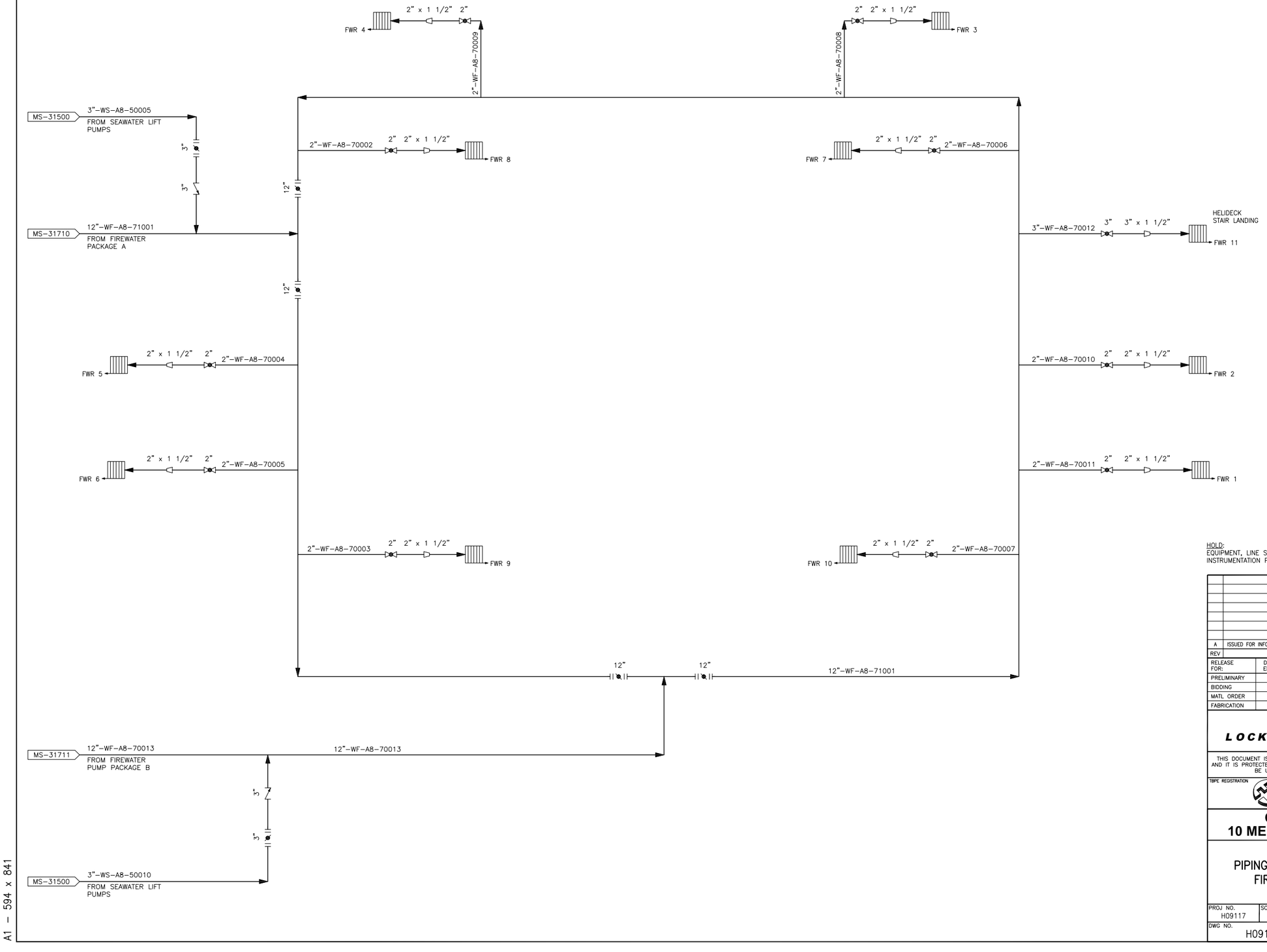
OTEC CONCEPT
10 MEGAWATT PLATFORM

PIPING & INSTRUMENT DIAGRAM
FIREWATER PUMP B

PROJ NO.	SCALE	DRAWN	DATE	CHECKED
H09117	AS NOTED	DTG	07–14–10	

DWG NO.	SHT	REV
H09117–T–DWG–MS–31711	01	A

A1 – 594 x 841



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INSTRUMENTATION PRELIMINARY

REV	DESCRIPTION	BY	DATE
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RELEASE FOR:	DEPT ENGR	PROJ ENGR	DESIGN ENGR	DESIGN LEAD	DATE
PRELIMINARY					
BIDDING					
MATL ORDER					
FABRICATION					

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Houston Offshore ENGINEERING

OTEC CONCEPT
10 MEGAWATT PLATFORM

PIPING & INSTRUMENT DIAGRAM
FIREWATER DISTRIBUTION

PROJ NO.	SCALE	DRAWN	DATE	CHECKED
H09117	AS NOTED	DTG	07-14-10	

DWG NO.	SHT	REV
H09117-T-DWG-MS-31712	01	A

A1 - 594 x 841

CS–8010A
LUBE OIL SKID

XM–8010A
TURBINE GENERATOR
RATING: 10 MVA

MS–31500
6"–WS–A8–50001
FROM SEAWATER LIFT PUMPS
6" x 4"
4"
4"–WS–50015–A8
CS–8010A
XM–8010A
4"
VENT TO SAFE LOCATION
2"–VA–80018–A1
FLAME ARRESTOR
LUBE OIL VENT MIST EXTRACTOR
PI
TI
PT
TT
12"
TURBINE
GENERATOR
MI
MT
OIL PRECIPITATION
VACUUM
2"
38"
38"–XX–80006–A1
AMMONIA TO REMORA
(HOLD)
2"–XX–80005–A1
AMMONIA FROM OIL SEPARATION SYSTEM
2"–XX–80006–A1
AMMONIA TO OIL SEPARATION SYSTEM
(HOLD)
32"–XX–80017–A1
AMMONIA FROM REMORA
32"
VACCUM
MS–31221
6"–XX–22001–A1
AMMONIA FROM AMMONIA STORAGE TANKS
4"–WS–80016–A8
L.O. FILTER DRAIN
SKID DRAIN PAN
2" L.O. TANK DRAIN
DRAIN PAN
UA 8010
UDA 8010
TURBINE/GENERATOR CONTROL PANEL (LOCATED IN MCC ROOM)
XY
I
2"–DO–80020–A1
2"–DO–A1–56003
OD
MS–31560
TO OPEN DRAIN SYSTEM
4"–WS–80019–A8
OVERBOARD
OVERBOARD

HOLD:
EQUIPMENT, LINE SIZING, & INSTRUMENTATION PRELIMINARY

REV	DESCRIPTION	BY	DATE
A	ISSUED FOR INFORMATION ONLY	PAK	07/16/10

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PRELIMINARY					
BIDDING					
MATL ORDER					
FABRICATION					

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OTEC CONCEPT
10 MEGAWATT PLATFORM

PIPING & INSTRUMENT DIAGRAM
TURBINE GENERATOR A

PROJ NO.	SCALE	DRAWN	DATE	CHECKED
H09117	AS NOTED	DTG	07–12–10	

DWG NO.	SHT	REV
H09117–T–DWG–MS–31800	01	A

A1 – 594 x 841

CS–8010B
LUBE OIL SKID

XM–8010B
TURBINE GENERATOR
RATING: 10 MVA

MS–31500 6"–WS–A8–50006 FROM SEAWATER LIFT PUMPS
6" x 4"
4"
4"–WS–A8–500010
4"
VENT TO SAFE LOCATION
2"–VA–A1–80004
CS–8010B
XM–8010B
FLAME ARRESTOR
LUBE OIL VENT MIST EXTRACTOR
PI
TI
PT
TT
2" OIL PRECIPITATION
2" VACUUM
38"
38"–XX–A1–80014 AMMONIA TO REMORA (HOLD)
2"–XX–A1–80015 AMMONIA FROM OIL SEPERATION SYSTEM (HOLD)
2"–XX–A1–80021 AMMONIA TO OIL SEPERATION SYSTEM (HOLD)
12"
TURBINE
GENERATOR
(HOLD) 32"–XX–A1–80012 AMMONIA FROM REMORA
32"
2"
VACCUM
MI
MT
MS–31220 6"–XX–A1–22001 AMMONIA FROM AMMONIA STORAGE TANKS
4"–WS–A8–80011
L.O. FILTER DRAIN
SKID DRAIN PAN
2" L.O. TANK DRAIN
DRAIN PAN
4"–WS–A8–80013
UA 8010
UDA 8010
TURBINE/GENERATOR CONTROL PANEL (LOCATED IN MCC ROOM)
XY
MWL + 0m
DEPTH –3m
2"–DO–A1–80007
2"–DO–A1–56002
DO MS–31560
TO OPEN DRAIN SYSTEM

HOLD:
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INSTRUMENTATION PRELIMINARY

REV	DESCRIPTION	BY	DATE
A	ISSUED FOR INFORMATION ONLY	PAK	07–16–10

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PRELIMINARY					
BIDDING					
MATL ORDER					
FABRICATION					

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Houston Offshore ENGINEERING

OTEC CONCEPT
10 MEGAWATT PLATFORM

PIPING & INSTRUMENT DIAGRAM
TURBINE GENERATOR B

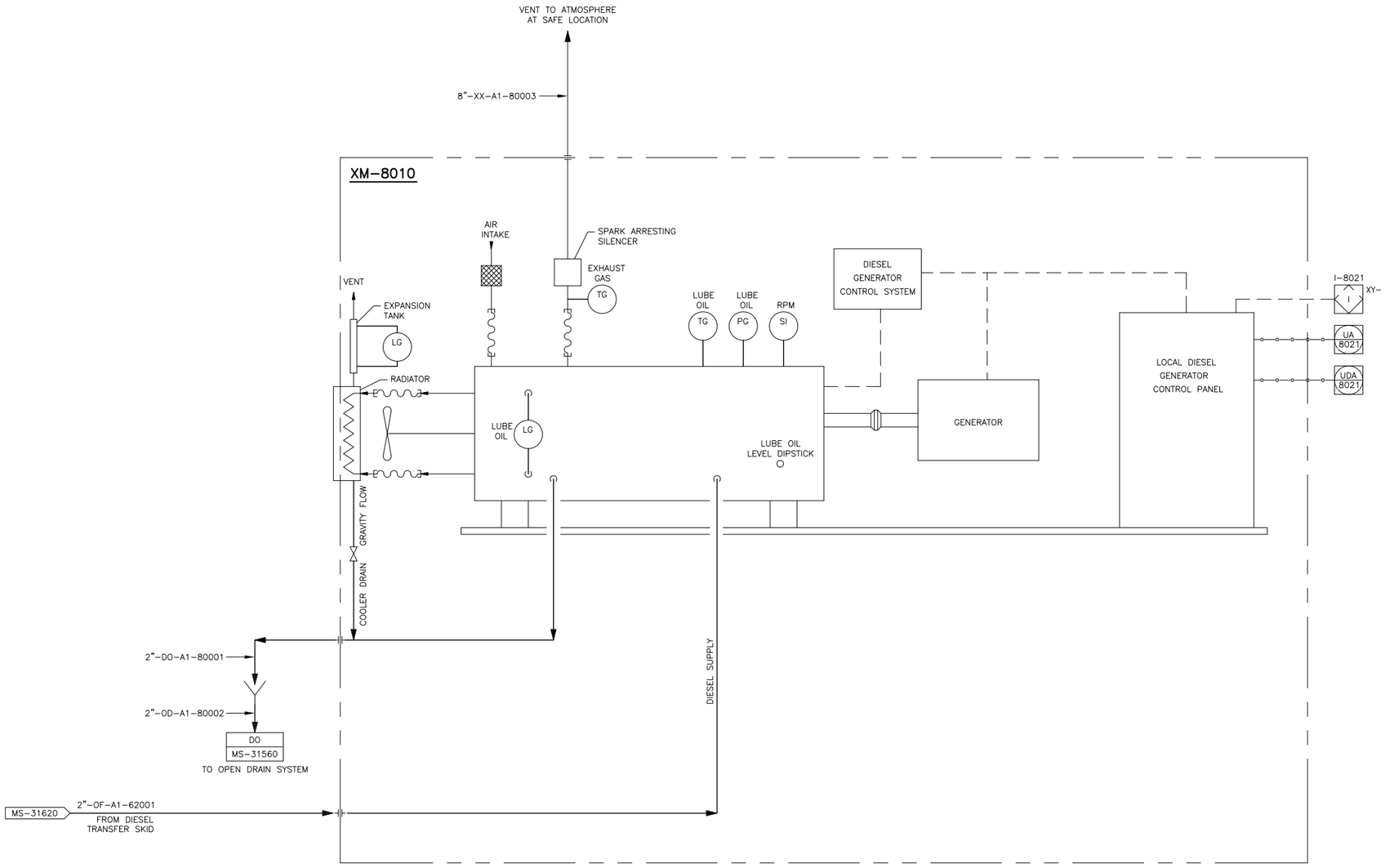
PROJ NO.	SCALE	DRAWN	DATE	CHECKED
H09117	AS NOTED	DTG	07–13–10	

DWG NO. H09117–T–DWG–MS–31801 SHT 01 REV A

A1 – 594 x 841

XM–8010

AUXILIARY GENERATOR
RATING: 3.1 MVA



HOLD:
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INSTRUMENTATION PRELIMINARY

REV	DESCRIPTION	BY	DATE
A	ISSUED FOR INFORMATION ONLY	PAK	07–16–10

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PRELIMINARY					
BIDDING					
MATL ORDER					
FABRICATION					

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OTEC CONCEPT
10 MEGAWATT PLATFORM

PIPING & INSTRUMENT DIAGRAM
AUXILIARY GENERATOR

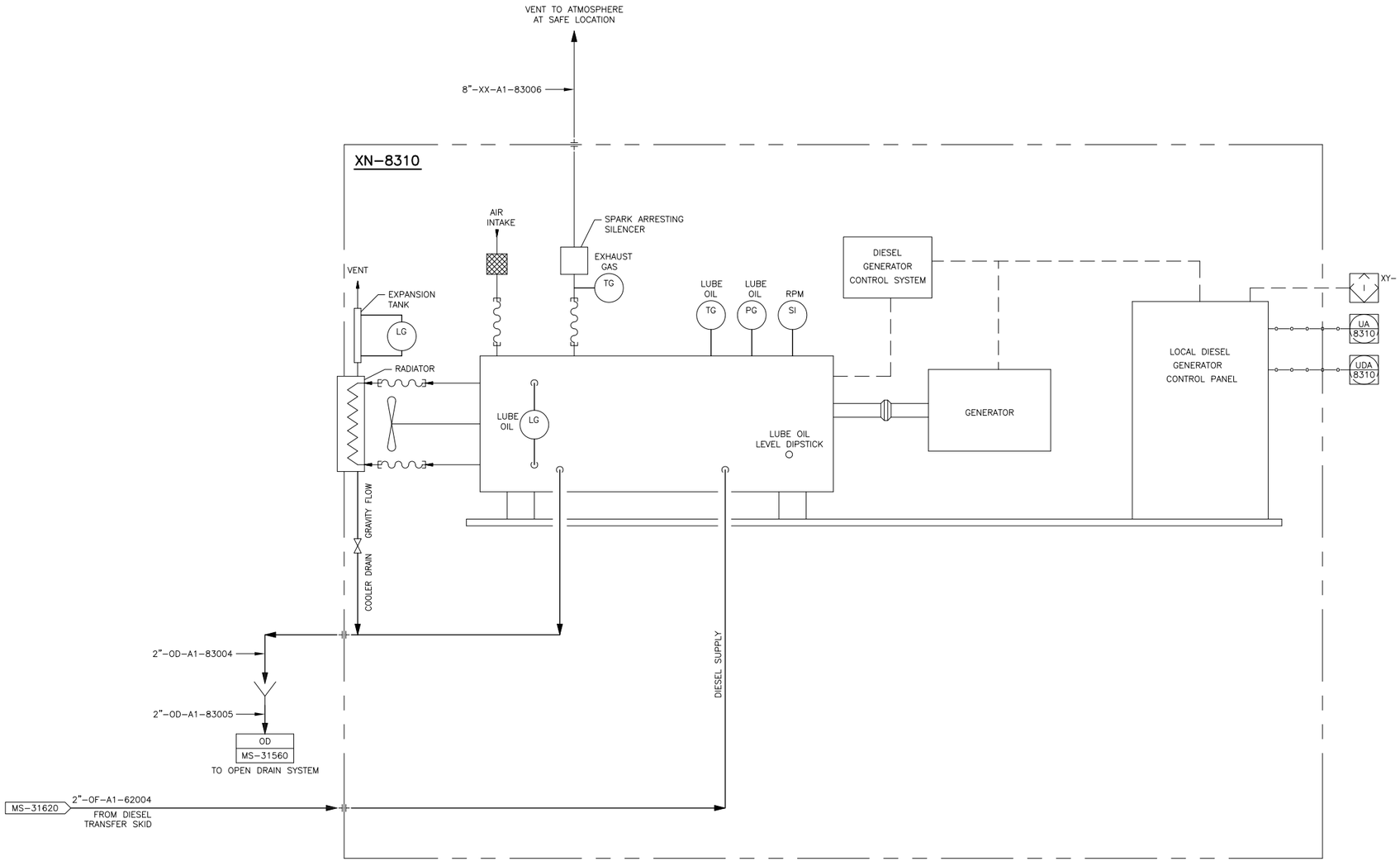
PROJ NO.	SCALE	DRAWN	DATE	CHECKED
H09117	AS NOTED	DTG	07–08–10	

DWG NO.	SHT	REV
H09117–T–DWG–MS–31804	01	A

A1 – 594 x 841

XN–8310

EMERGENCY GENERATOR
RATING: 750 kVA



HOLD:
EQUIPMENT, LINE SIZING, &
INSTRUMENTATION PRELIMINARY

REV	DESCRIPTION	BY	DATE
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MATL ORDER					
FABRICATION					

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OTEC CONCEPT
10 MEGAWATT PLATFORM

PIPING & INSTRUMENT DIAGRAM
EMERGENCY GENERATOR

PROJ NO.	SCALE	DRAWN	DATE	CHECKED
H09117	AS NOTED	DTG	07–08–10	

DWG NO.	SHT	REV
H09117–T–DWG–MS–31830	01	A

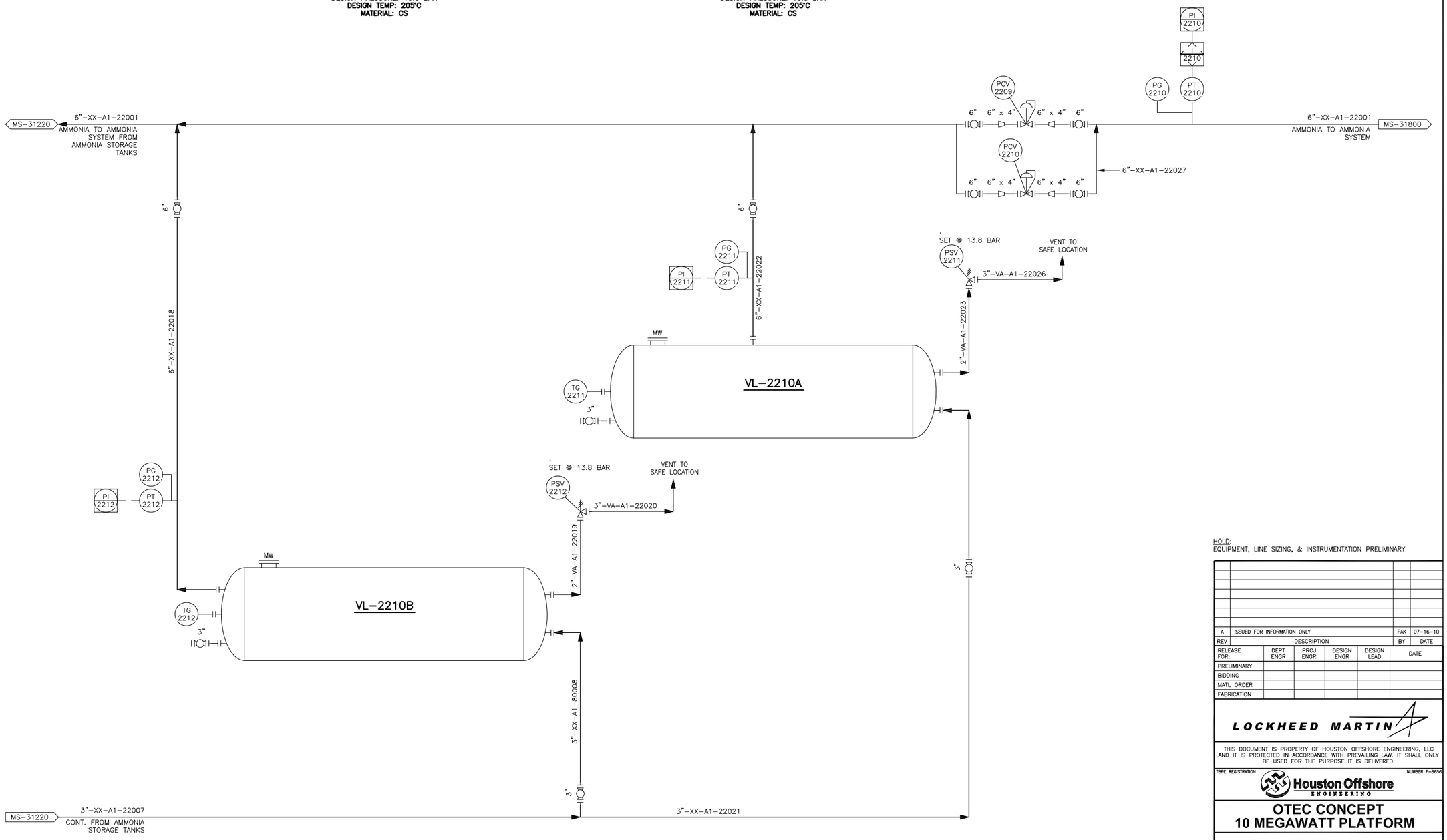
A1 – 594 x 841

VL-2210B

AMMONIA STORAGE TANK
DIMENSIONS: 2.5m OD X 16.9m OAL
CAPACITY: 87 CU METERS
DESIGN PRESSURE: 13.8 BAR
DESIGN TEMP: 205°C
MATERIAL: CS

VL-2210A

AMMONIA STORAGE TANK
DIMENSIONS: 2.5m OD X 16.9m OAL
CAPACITY: 87 CU METERS
DESIGN PRESSURE: 13.8 BAR
DESIGN TEMP: 205°C
MATERIAL: CS



HOLD:
EQUIPMENT, LINE SIZING, & INSTRUMENTATION PRELIMINARY

REV	DESCRIPTION	BY	DATE
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PRELIMINARY					
BIDDING					
MATL ORDER					
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OTEC CONCEPT
10 MEGAWATT PLATFORM

PIPING & INSTRUMENT DIAGRAM
AMMONIA STORAGE TANKS

PROJ NO.	SCALE	DRAWN	DATE	CHECKED
H09117	AS NOTED	DTG	07-12-10	

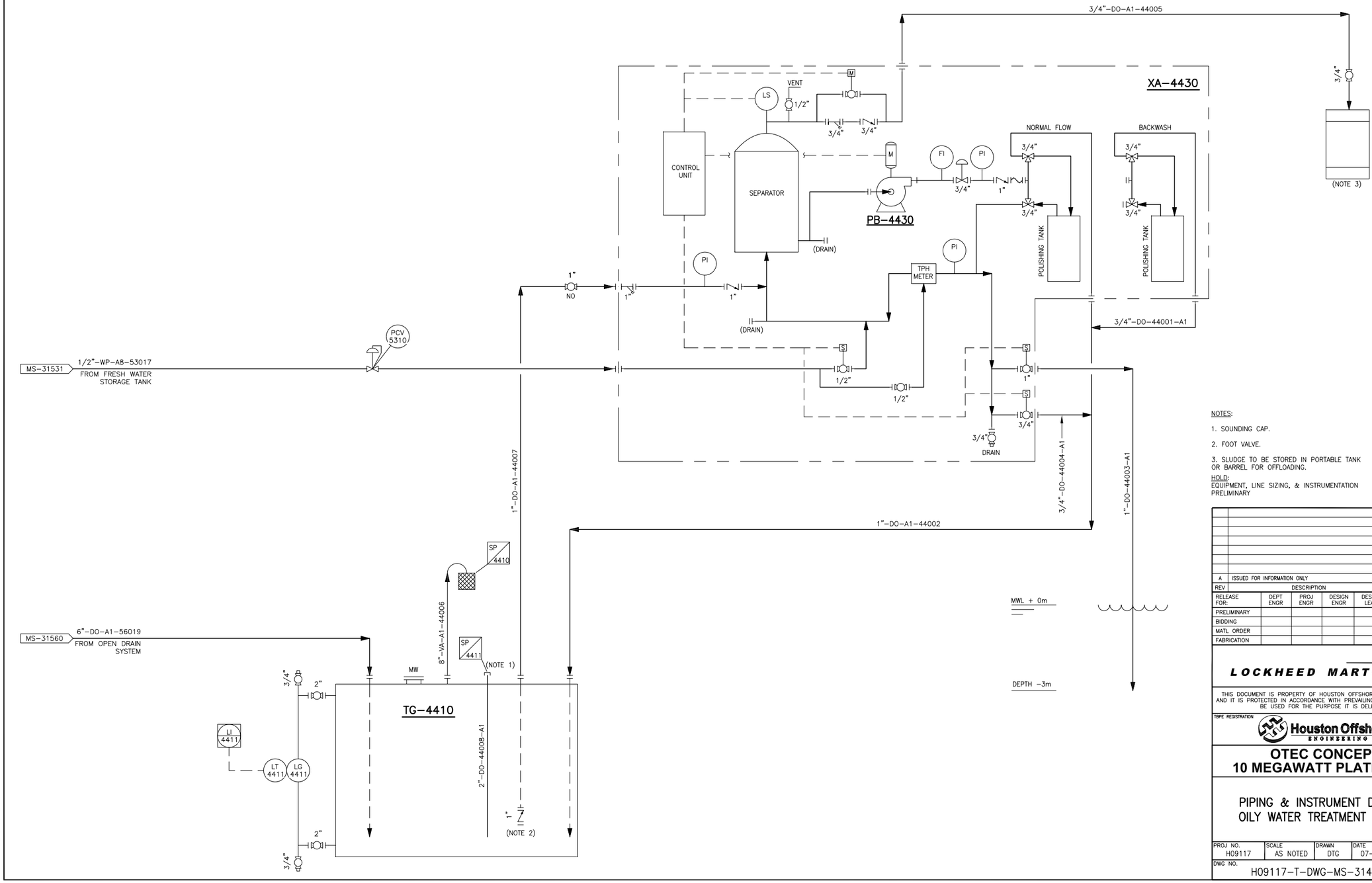
DWG NO.	SHT	REV
H09117-T-DWG-MS-31221	01	A

A1 - 594 x 841

TG–4410
TOPSIDES OILY WATER SUMP TANK
SIZE: 2.4m x 1.2m x 1.2m
CAPACITY: 3.78 CU. METERS

PB–4430
OILY WATER SEPARATOR
PROCESS PUMP

XA–4430
OILY WATER SEPARATOR
CAPACITY: 2.3 CU. METERS/HR



NOTES:

1. SOUNDING CAP.
2. FOOT VALVE.
3. SLUDGE TO BE STORED IN PORTABLE TANK OR BARREL FOR OFFLOADING.

HOLD:
EQUIPMENT, LINE SIZING, & INSTRUMENTATION PRELIMINARY

REV	DESCRIPTION	BY	DATE
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MATL ORDER					
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OTEC CONCEPT 10 MEGAWATT PLATFORM

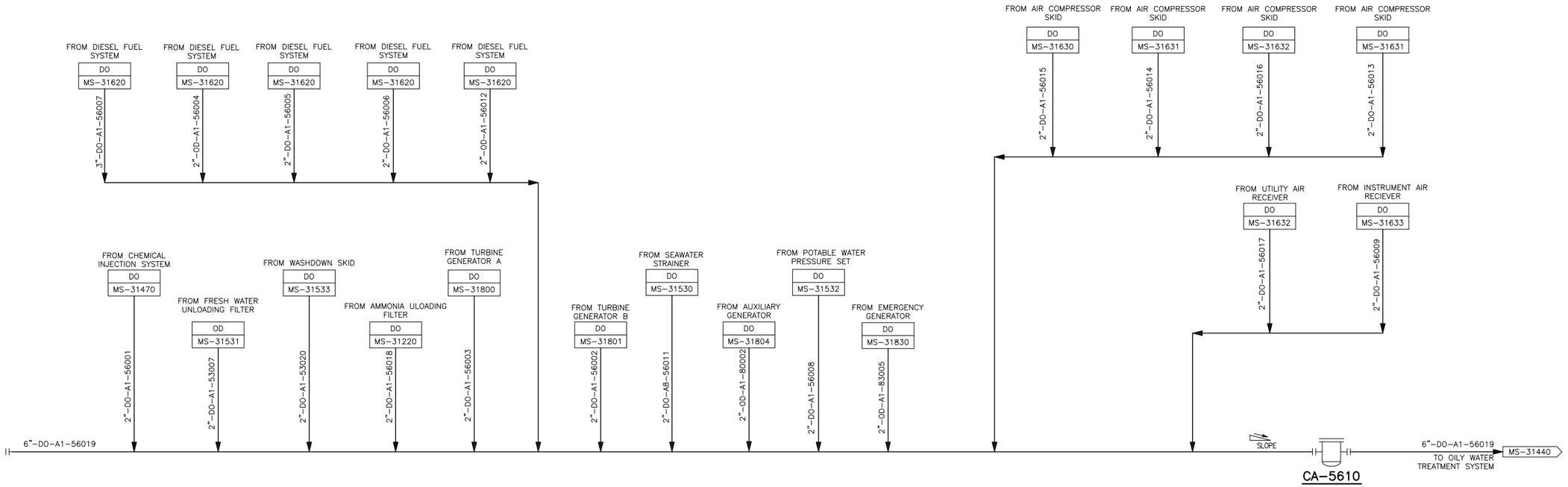
PIPING & INSTRUMENT DIAGRAM OILY WATER TREATMENT SYSTEM

PROJ NO.	SCALE	DRAWN	DATE	CHECKED
H09117	AS NOTED	DTG	07–12–10	

DWG NO.	SHT	REV
H09117–T–DWG–MS–31440	01	A

A1 – 594 x 841

CA–5610
OPEN DRAIN FILTER



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OTEC CONCEPT
10 MEGAWATT PLATFORM

PIPING & INSTRUMENT DIAGRAM
OPEN DRAIN SYSTEM

PROJ NO.	SCALE	DRAWN	DATE	CHECKED
H09117	AS NOTED	DTG	06–30–10	

DWG NO.	SHT	REV
H09117–T–DWG–MS–31560	01	A

A1 – 594 x 841

X:\Halyard\H09117 NAFAC–OTEC Platform Pre–FEED\Marine Systems\PID\OTEC\PID DWG\H09117–T–DWG–MS–31560.dwg

TA-6220
DIESEL STORAGE TANK
SIZE: 2.7M.O.D. X 9.1M HT
CAPACITY: 37 CU. METERS

MA-7310B
PEDISTAL CRANE

XX-6210
DIESEL TRANSFER SKID
CAPACITY: 10 CU. METERS/HR

CA-6210
DIESEL FUEL FILTER

PE-6210A
DIESEL FUEL TRANSFER PUMP

PE-6210B
DIESEL FUEL TRANSFER PUMP

VJ-6210
DIESEL FUEL COALESCER

MA-7310B

SP 6210
BUG SCREEN

ACCESS HOLE

GRATING FLOOR

3"-DO-A1-62013

3"-DO-A1-56007

OD MS-31560

TO OPEN DRAIN SYSTEM

6"-VA-A1-62012

2"-OD-A1-62010

2"-DO-A1-56006

OD MS-31560

TO OPEN DRAIN SYSTEM

TA-6220

LT 6222
LG 6222
MAG
LI 6222

LG 6221
LT 6221
6221
LI 6221

DOWNCOMER PIPE

18" MW

LG 6223

2"-DO-A1-62002

2"-DO-A1-56005

DO MS-31560

TO OPEN DRAIN SYSTEM

3"-OF-A1-62007

3"-OF-A1-62008

2"-OD-A1-56004

DO MS-31560

TO OPEN DRAIN SYSTEM

PCV 6210
PG 6210
2"-OF-A1-62011-A1
2"-OF-A1-62003

XX-6210

SET AT ____ PSIG
PSV
PDG
LO
2"-OF-A1-62001
TO AUXILIARY DIESEL GENERATOR
MS-31804
2"-OF-A1-62004
TO EMERGENCY GENERATOR
MS-31830

VJ-6210

2"-DO-A1-62009
2"-OD-A1-56012
DO MS-31560
TO OPEN DRAIN SYSTEM

SDV
PG
3"X2"
RUN STOP
HS HS
MCC
M

PE-6210A
PE-6210B

1 1/2E2
SET AT
150 PSIG
PSV
PDG
LO

CA-6210

FILL CONNECTION
3"-OF-A1-62006
SP 6211

NC

HOLD:
EQUIPMENT, LINE SIZING, &
INSTRUMENTATION PRELIMINARY

REV	DESCRIPTION	BY	DATE
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TBPE REGISTRATION NUMBER F-8656
Houston Offshore ENGINEERING

OTEC CONCEPT
10 MEGAWATT PLATFORM

PIPING & INSTRUMENT DIAGRAM
DIESEL FUEL SYSTEM

PROJ NO.	SCALE	DRAWN	DATE	CHECKED
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DWG NO. H09117-T-DWG-MS-31620 SHT 01 REV A

A1 - 594 x 841

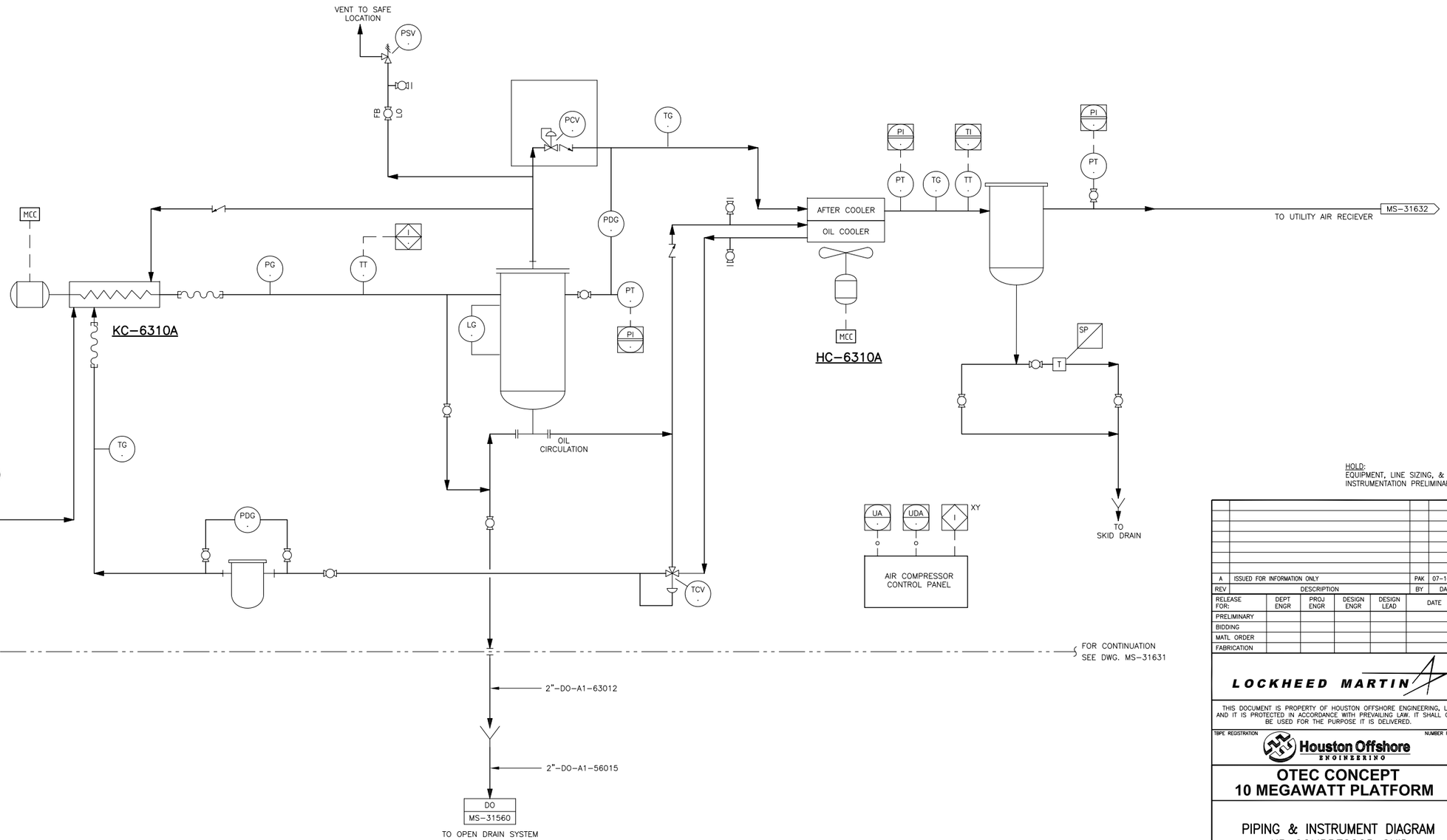
KZ-6310
AIR COMPRESSOR SKID
424 CU METERS/HR @ 10.3 BARG

KC-6310A
AIR COMPRESSOR
424 CU METERS/HR @ 10.3 BARG

HC-6310A
AIR COOLER FAN
3.4 BHP

FOR CONTINUATION
SEE DWG. MS-31631

KZ-6310



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OTEC CONCEPT
10 MEGAWATT PLATFORM

PIPING & INSTRUMENT DIAGRAM
AIR COMPRESSOR SKID

PROJ NO.	SCALE	DRAWN	DATE	CHECKED
H09117	AS NOTED	DTG	07-13-10	

DWG NO.	SHT	REV
H09117-T-DWG-MS-31630	01	A

A1 - 594 x 841

KZ–6310
AIR COMPRESSOR SKID
424 CU. METERS/HR @ 10.3 BARG

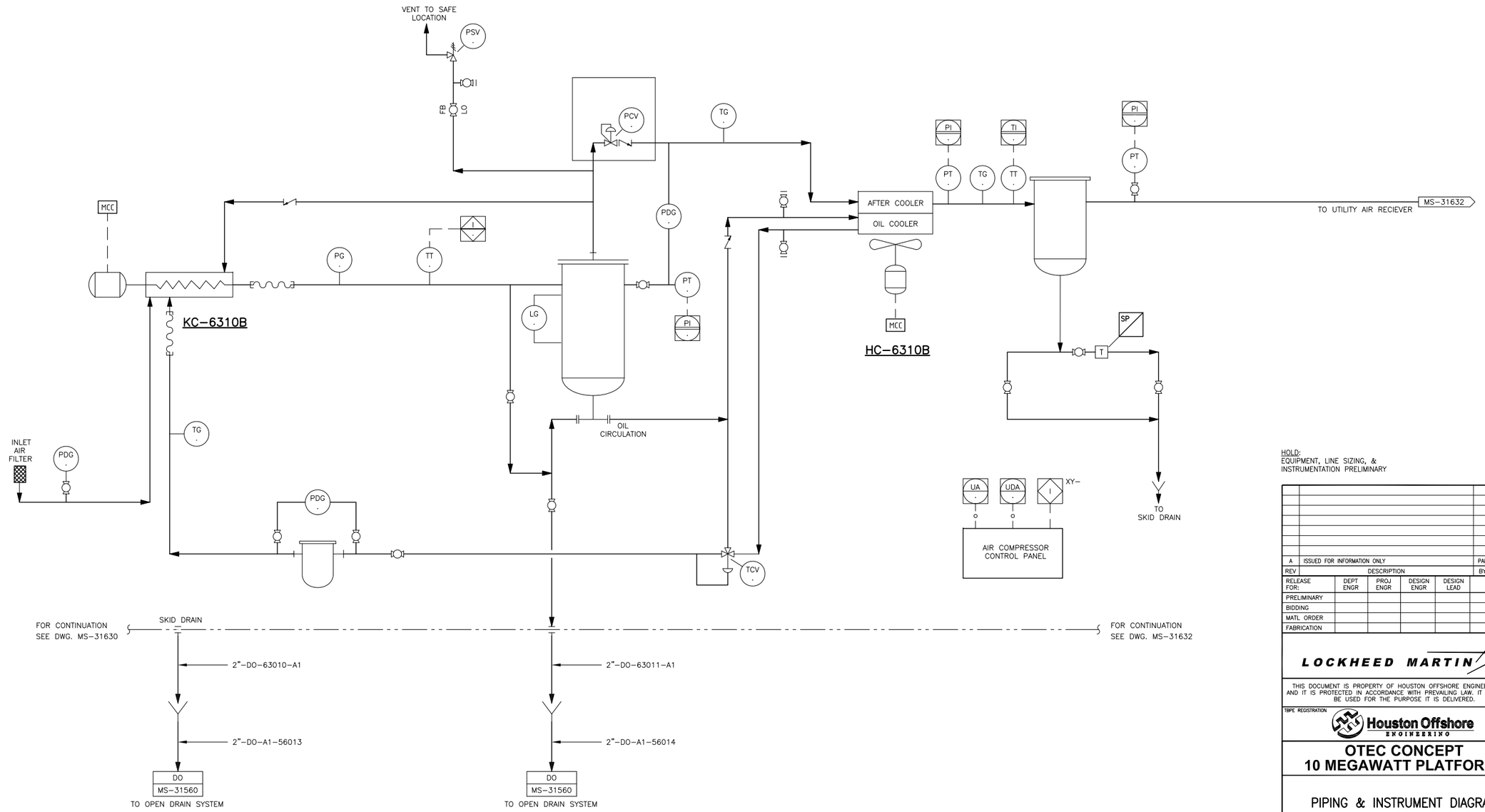
KC–6310B
AIR COMPRESSOR
424 CU. METERS/HR @ 10.3 BARG

HC–6310B
AIR COOLER FAN
3.4 BHP

FOR CONTINUATION
SEE DWG. MS–31630

FOR CONTINUATION
SEE DWG. MS–31632

KZ–6310



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INSTRUMENTATION PRELIMINARY

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PRELIMINARY					
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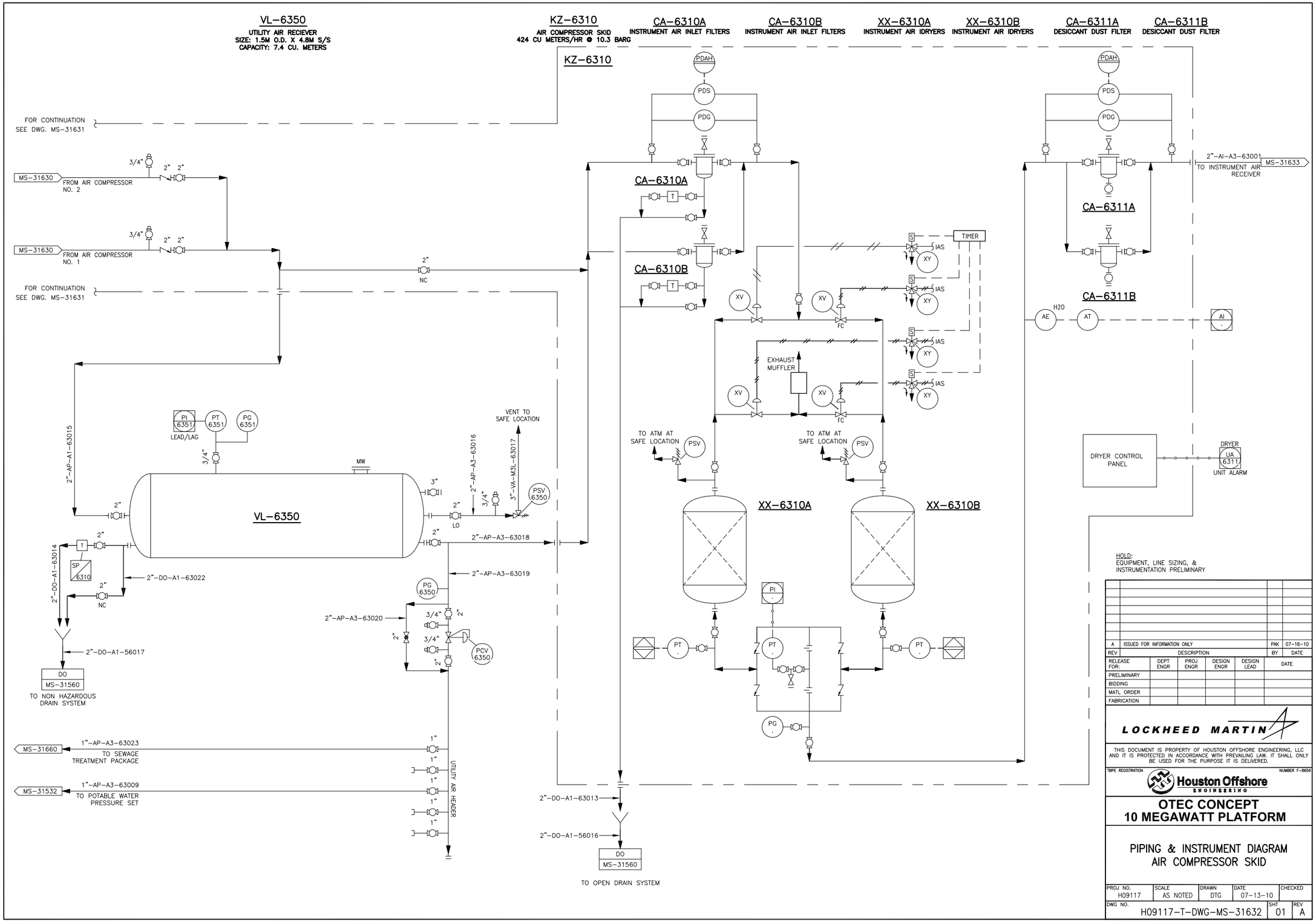
OTEC CONCEPT
10 MEGAWATT PLATFORM

PIPING & INSTRUMENT DIAGRAM
AIR COMPRESSOR SKID

PROJ NO.	SCALE	DRAWN	DATE	CHECKED
H09117	AS NOTED	DTG	07–13–10	

DWG NO.	SHT	REV
H09117–T–DWG–MS–31631	01	A

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PRELIMINARY					
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Houston Offshore ENGINEERING

OTEC CONCEPT
10 MEGAWATT PLATFORM

PIPING & INSTRUMENT DIAGRAM
AIR COMPRESSOR SKID

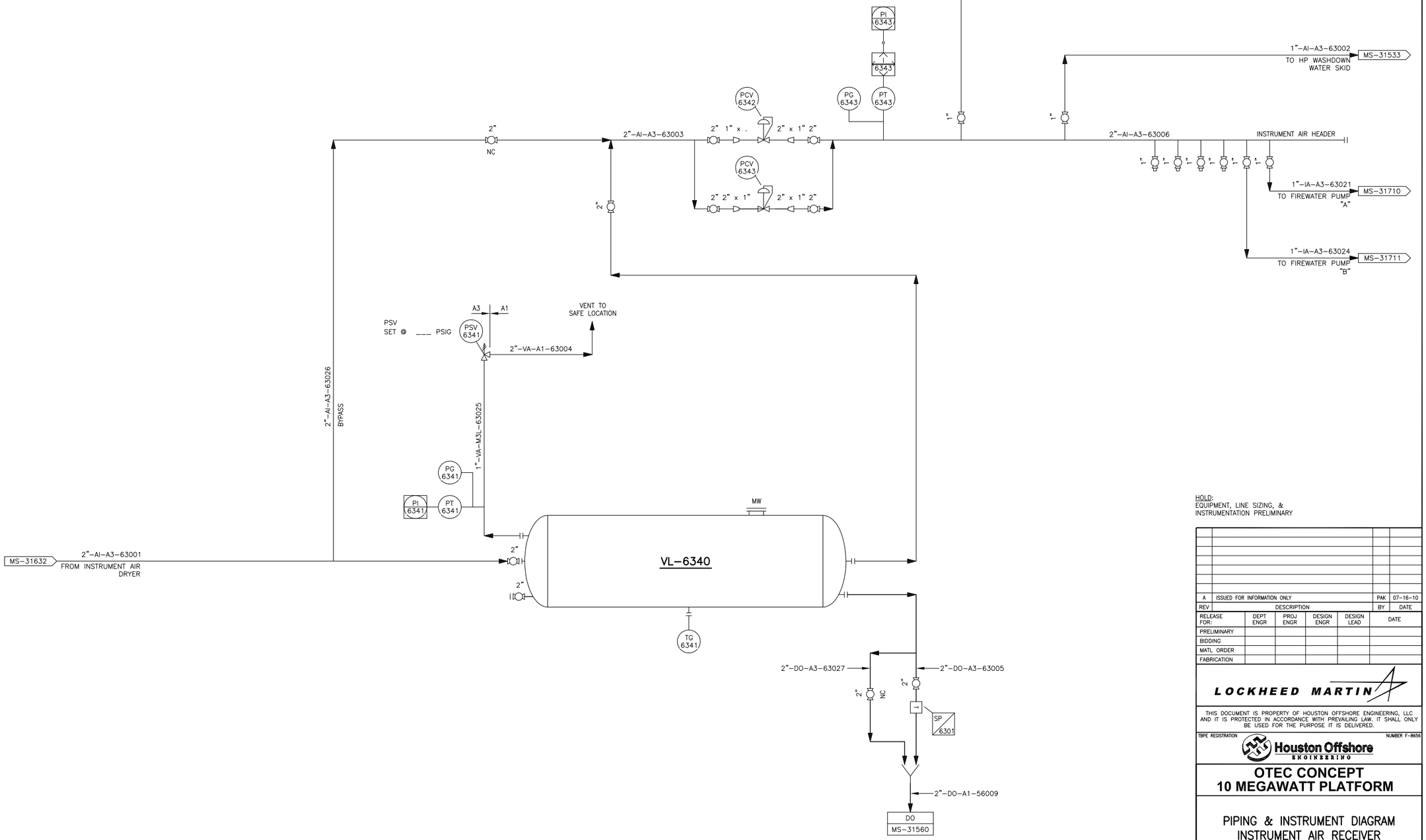
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DWG NO.	SHT	REV
H09117-T-DWG-MS-31632	01	A

A1 - 594 x 841

VL-6340

INSTRUMENT AIR RECIEVER
SIZE: 1.2m OD X 3.6m S/S
DESIGN PRESS: 14 BARG
DESIGN TEMP: 94°C
MATERIAL: CARBON STEEL
CAPACITY: 4 CU. METERS



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EQUIPMENT, LINE SIZING, & INSTRUMENTATION PRELIMINARY

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A	ISSUED FOR INFORMATION ONLY	PAK	07-16-10

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OTEC CONCEPT
10 MEGAWATT PLATFORM

PIPING & INSTRUMENT DIAGRAM
INSTRUMENT AIR RECEIVER

PROJ NO.	SCALE	DRAWN	DATE	CHECKED
H09117	AS NOTED	DTG	07-06-10	

DWG NO.	SHT	REV
H09117-T-DWG-MS-31633	01	A

A1 - 594 x 841

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-5
Platform Electrical and Control System Diagrams
OTEC-2010-001

17 September 2010

Prepared for:

Naval Facilities Engineering Command
Naval Facilities Engineering Service Center (NFESC)
1100 23rd Avenue
Port Hueneme, CA 93043-4370
Attn: Mr. Brian Cable, Contracting Officer Representative

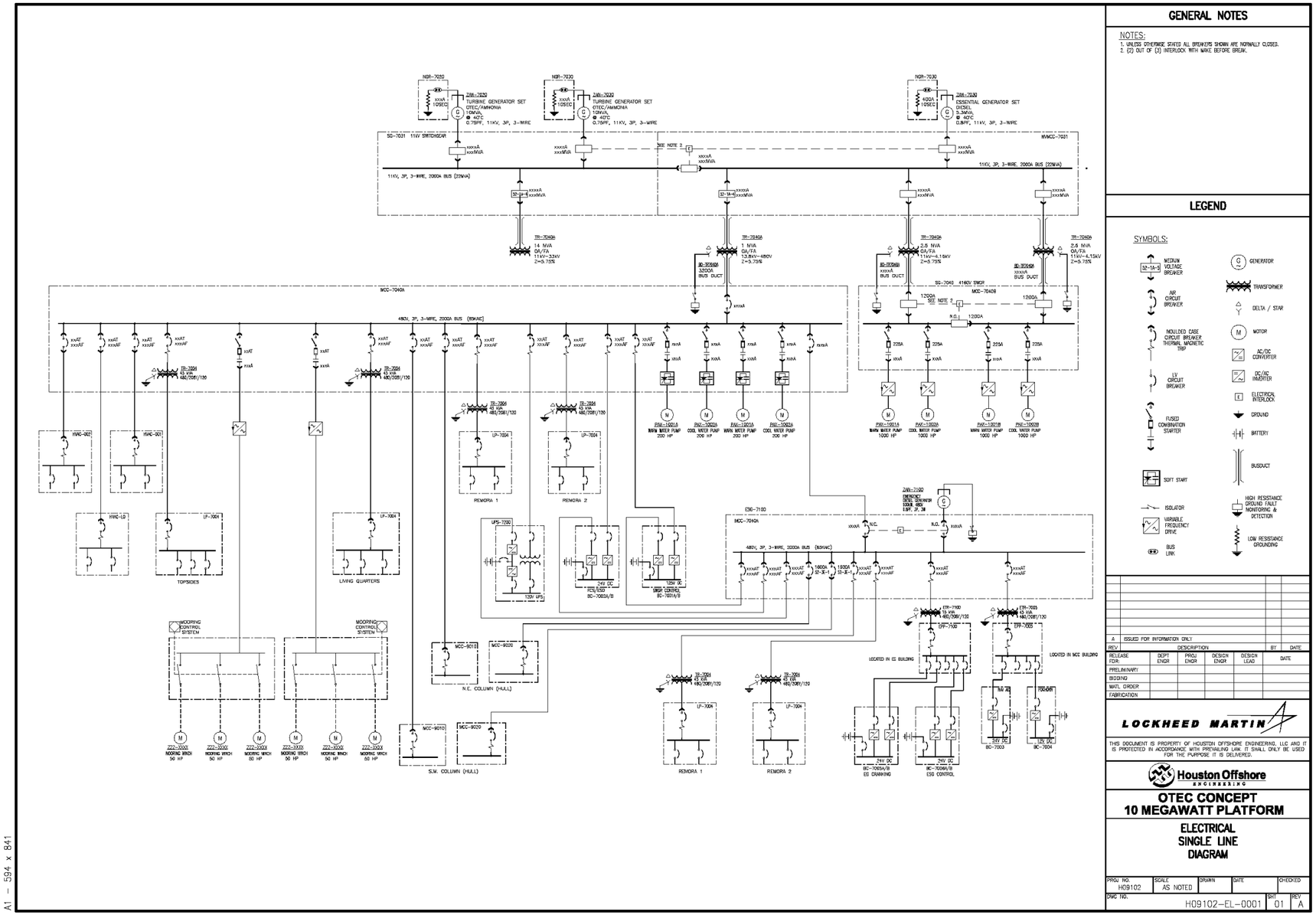
Prepared by:

Lockheed Martin MS2
9500 Godwin Drive
Manassas, VA 20110

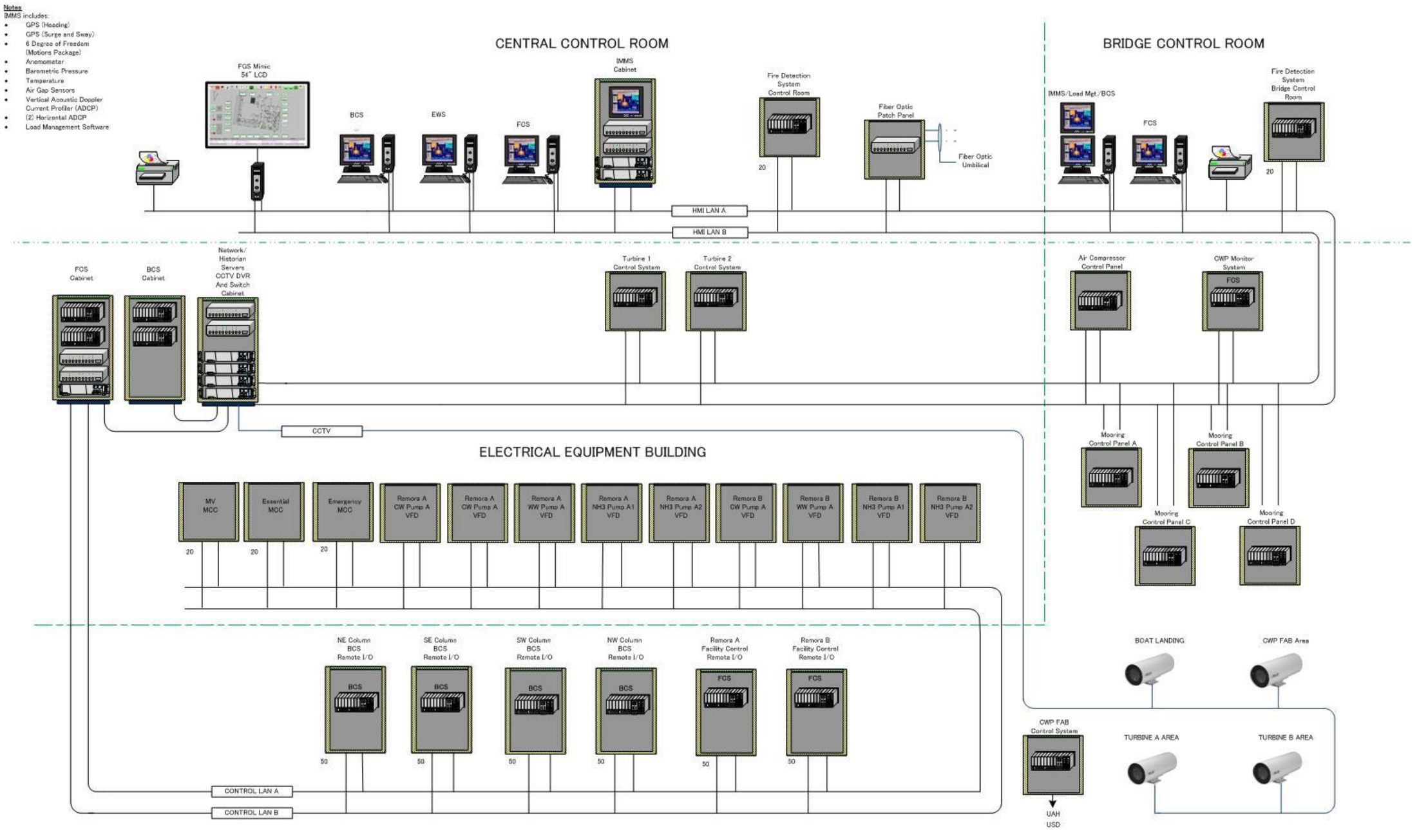
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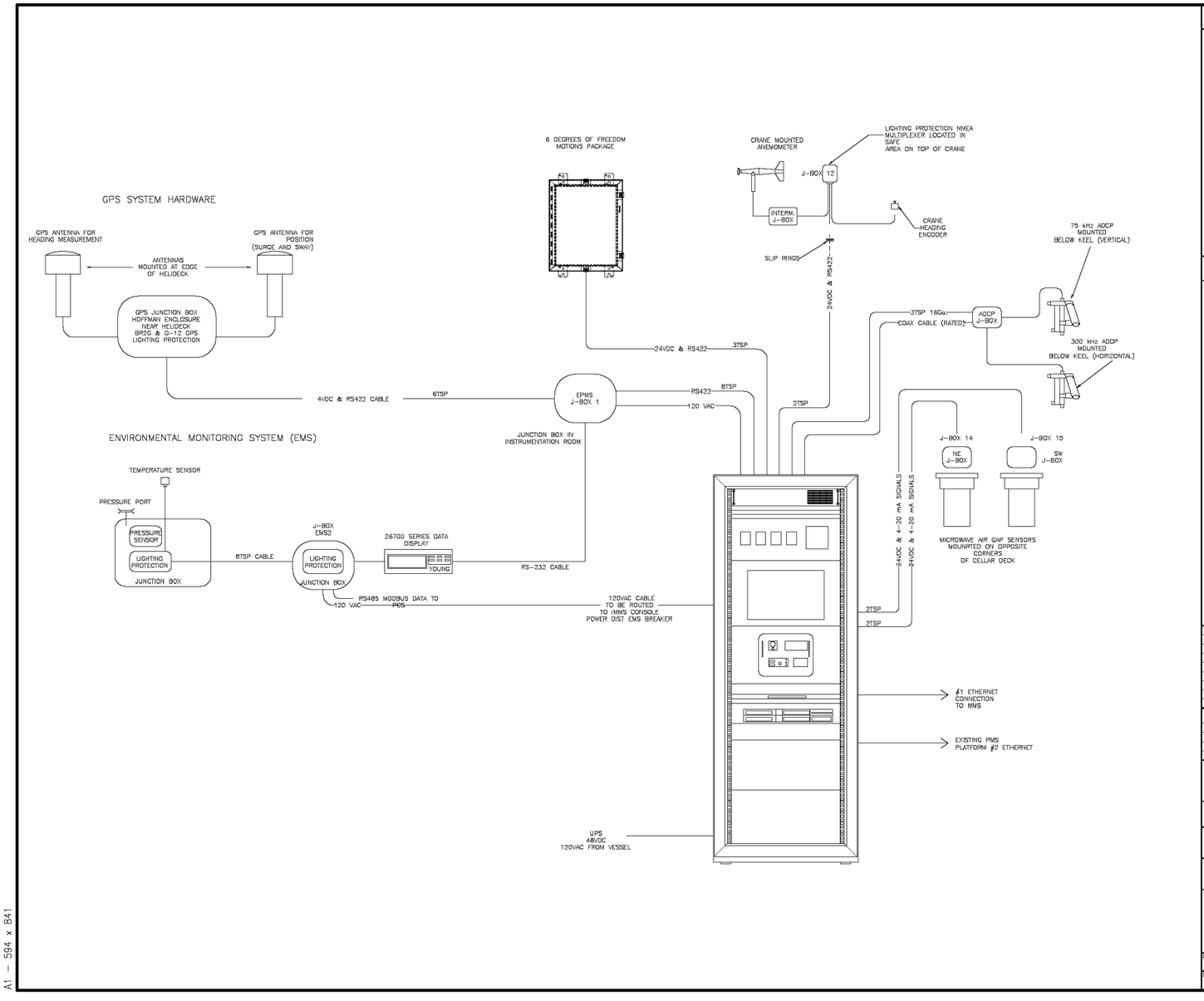
APPENDIX 3.3.1-5 – Platform Electrical and Control System Diagrams

1. Electrical Single Line Diagram
2. ICSS Architecture Diagram (Sketch)
3. IMMS Block Diagram
4. Electrical Equipment Room Layout


SG-7031 11kV SWITCHGEAR
MMCC-7031
11kV, 3P, 3-WIRE, 2000A BUS (22MVA)
MCC-7040A
480V, 3P, 3-WIRE, 2000A BUS (80kVAC)
MCC-7040B
ESG-7100
REMORA 1
REMORA 2
TOPSIDES
LIVING QUARTERS
N.E. COLUMN (HULL)
S.W. COLUMN (HULL)
MOORING CONTROL SYSTEM
LOCATED IN ES BUILDING
LOCATED IN MCC BUILDING
GENERAL NOTES
NOTES:
1. UNLESS OTHERWISE STATED ALL BREAKERS SHOWN ARE NORMALLY CLOSED.
2. (2) OUT OF (3) INTERLOCK WITH MAKE BEFORE BREAK.
LEGEND
SYMBOLS:
MEDIUM VOLTAGE BREAKER
AIR CIRCUIT BREAKER
MOLDED CASE CIRCUIT BREAKER THERMAL MAGNETIC TRIP
LV CIRCUIT BREAKER
FUSED COMBINATION STARTER
SOFT START
ISOLATOR
VARIABLE FREQUENCY DRIVE
BUS LINK
GENERATOR
TRANSFORMER
DELTA / STAR
MOTOR
AC/DC CONVERTER
DC/AC INVERTER
ELECTRICAL INTERLOCK
GROUND
BATTERY
BUSDUCT
HIGH RESISTANCE GROUND FAULT MONITORING & DETECTION
LOW RESISTANCE GROUNDING
A ISSUED FOR INFORMATION ONLY
REV DESCRIPTION BY DATE
RELEASE FOR: DEPT ENGR PROJ ENGR DESIGN ENGR DESIGN LEAD DATE
PRELIMINARY
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OTEC CONCEPT
10 MEGAWATT PLATFORM
ELECTRICAL
SINGLE LINE
DIAGRAM
PROJ NO. H09102
SCALE AS NOTED
DRAWN
DATE
CHECKED
DWG NO. H09102-EL-0001
SHT 01
REV A

A1 - 594 x 841


Notes
IMMS includes:
GPS (Heading)
GPS (Surge and Sway)
6 Degree of Freedom (Motions Package)
Anemometer
Barometric Pressure
Temperature
Air Gap Sensors
Vertical Acoustic Doppler Current Profiler (ADCP)
(2) Horizontal ADCP
Load Management Software
CENTRAL CONTROL ROOM
BRIDGE CONTROL ROOM
FCS Mimic 54" LCD
BCS
EWS
FCS
IMMS Cabinet
Fire Detection System Control Room
Fiber Optic Patch Panel
Fiber Optic Umbilical
IMMS/Load Mgt/BCS
FCS
Fire Detection System Bridge Control Room
20
HMI LAN A
HMI LAN B
FCS Cabinet
BCS Cabinet
Network/ Historian Servers CCTV DVR And Switch Cabinet
Turbine 1 Control System
Turbine 2 Control System
Air Compressor Control Panel
CWP Monitor System
FCS
CCTV
ELECTRICAL EQUIPMENT BUILDING
MV MCC
Essential MCC
Emergency MCC
Remora A CW Pump A VFD
Remora A CW Pump A VFD
Remora A WW Pump A VFD
Remora A NH3 Pump A1 VFD
Remora A NH3 Pump A2 VFD
Remora B CW Pump A VFD
Remora B WW Pump A VFD
Remora B NH3 Pump A1 VFD
Remora B NH3 Pump A2 VFD
Mooring Control Panel A
Mooring Control Panel B
Mooring Control Panel C
Mooring Control Panel D
NE Column BCS Remote I/O
SE Column BCS Remote I/O
SW Column BCS Remote I/O
NW Column BCS Remote I/O
Remora A Facility Control Remote I/O
Remora B Facility Control Remote I/O
BCS
FCS
50
BOAT LANDING
CWP FAB Area
CWP FAB Control System
TURBINE A AREA
TURBINE B AREA
UAH
USD
CONTROL LAN A
CONTROL LAN B



KEY

GENERAL NOTES

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TDPC REGISTRATION NUMBER F-6056

Houston Offshore ENGINEERING

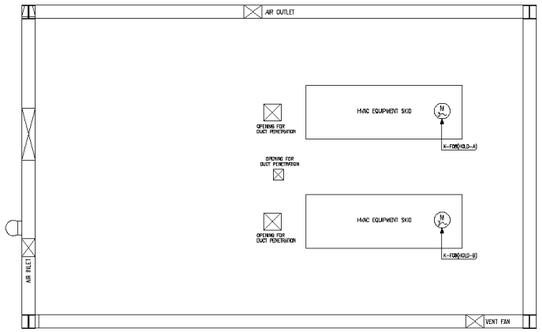
OTEC CONCEPT
10 MEGAWATT PLATFORM

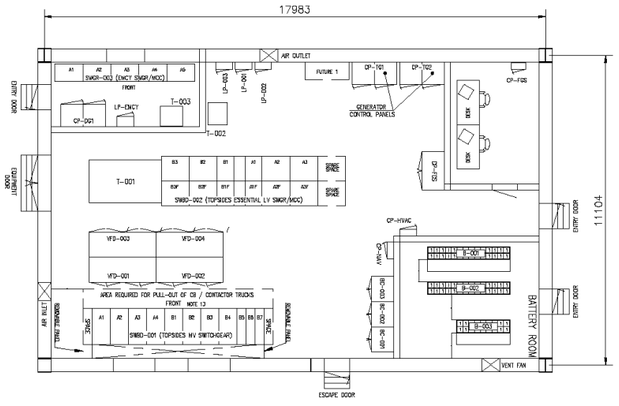
IMMS
BLOCK DIAGRAM

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H09102	NONE	OWMc	8/8/10	

DRG NO.	SHT	REV
H09102-H-0001	01	A

ROOF TOP




17983
11104
AIR OUTLET
FUTURE 1
CP-101
CP-102
CP-FDS
LP-003
LP-001
LP-002
GENERATOR CONTROL PANELS
DESK
DESK
SEAT
SWGR-002 (TOPSIDES ESSENTIAL LV SWGR/MCC)
T-001
T-002
T-003
LP-ENCY
CP-001
CP-HVAC
HVAC
HVAC
HVAC
VFD-003
VFD-004
VFD-001
VFD-002
AREA REQUIRED FOR PULL-OUT OF CB / CONTACTOR TRUCKS FRONT NOTE 13
SWGR-001 (TOPSIDES HV SWITCHGEAR)
SPARE
SPARE
SPARE

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-6
Deck Global Structural Analysis Results
OTEC-2010-001

17 September 2010

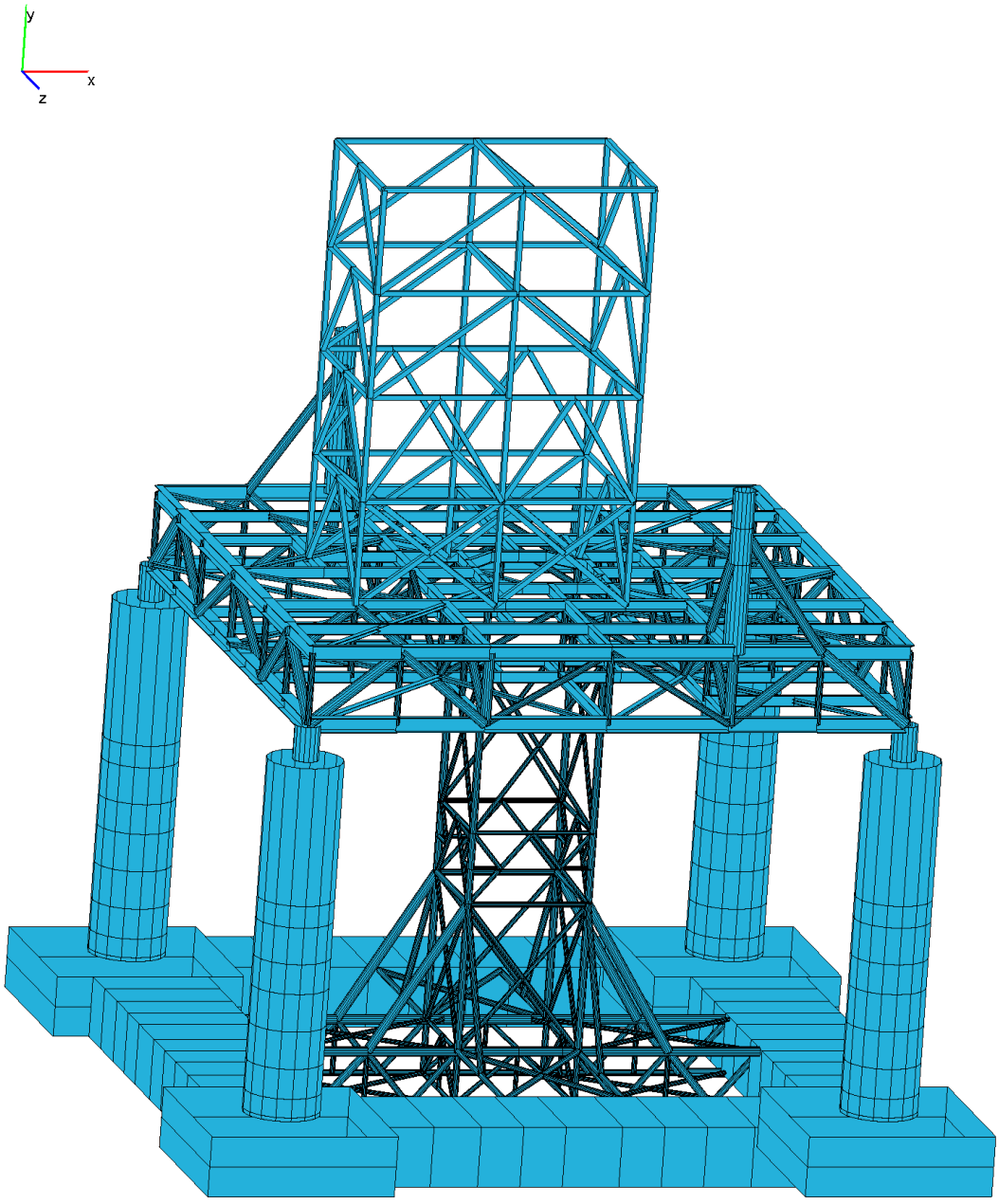
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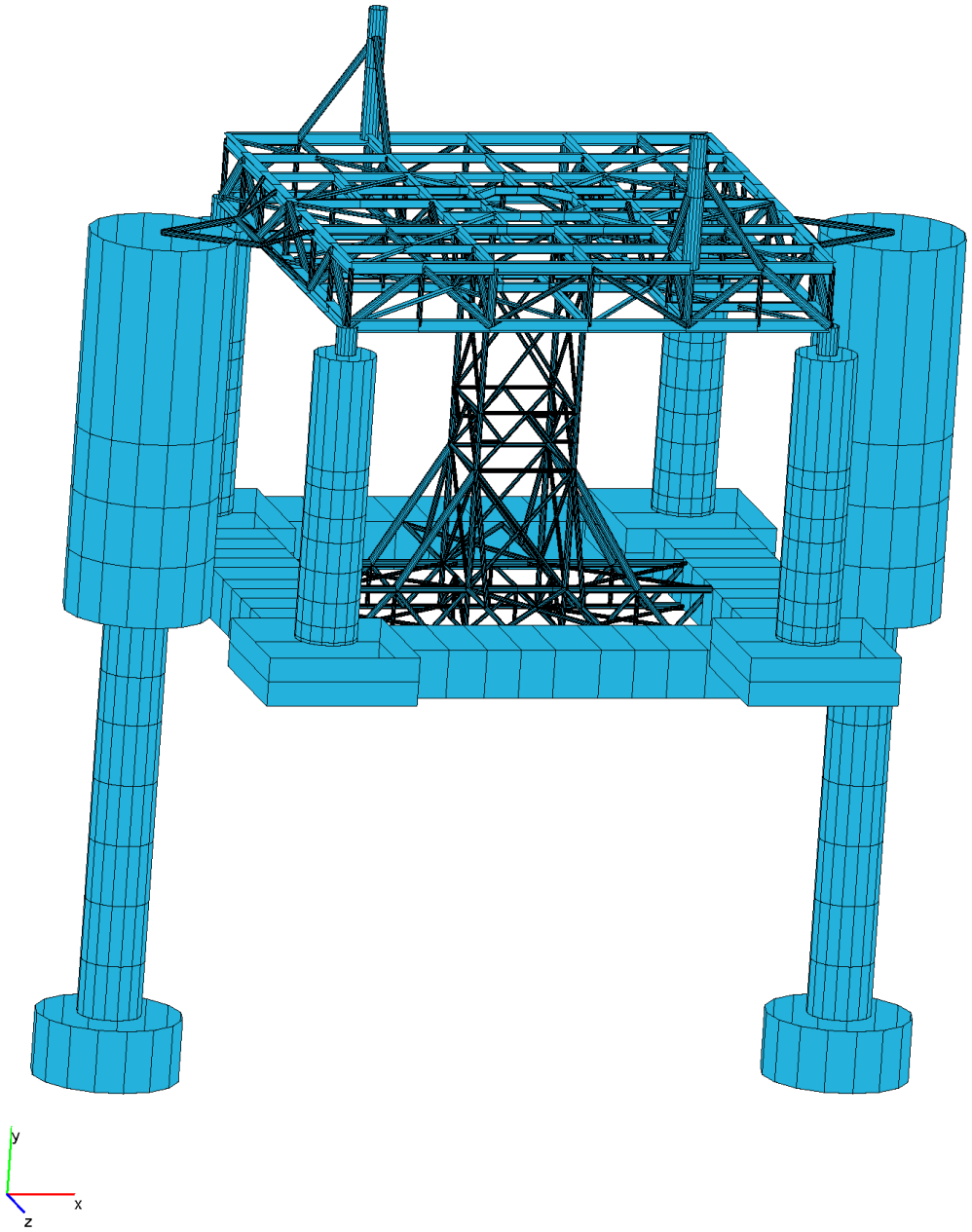
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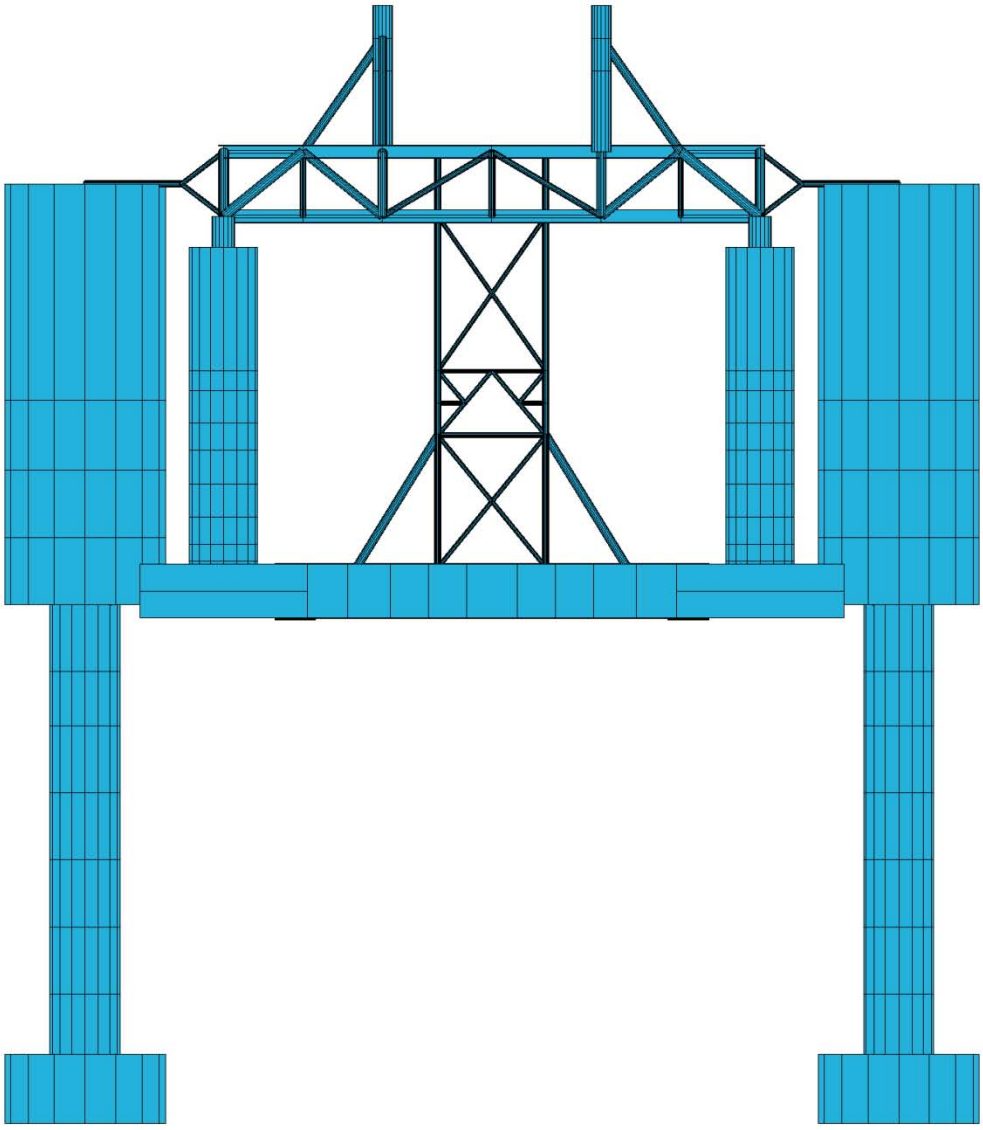
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OTEC, Fabrication Phase

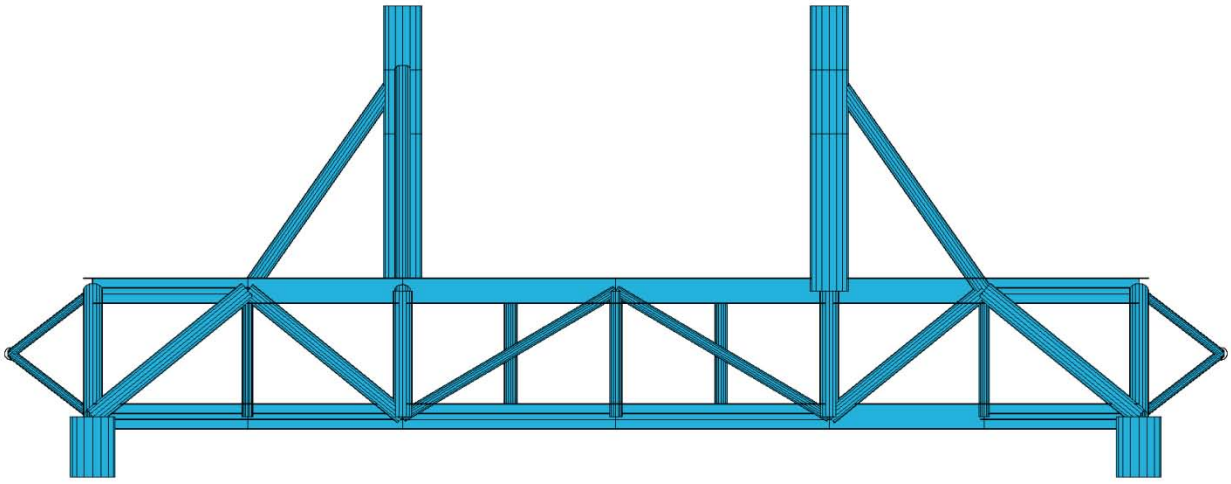


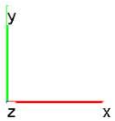
OTEC, Full Production Phase



OTEC, Full Production Phase

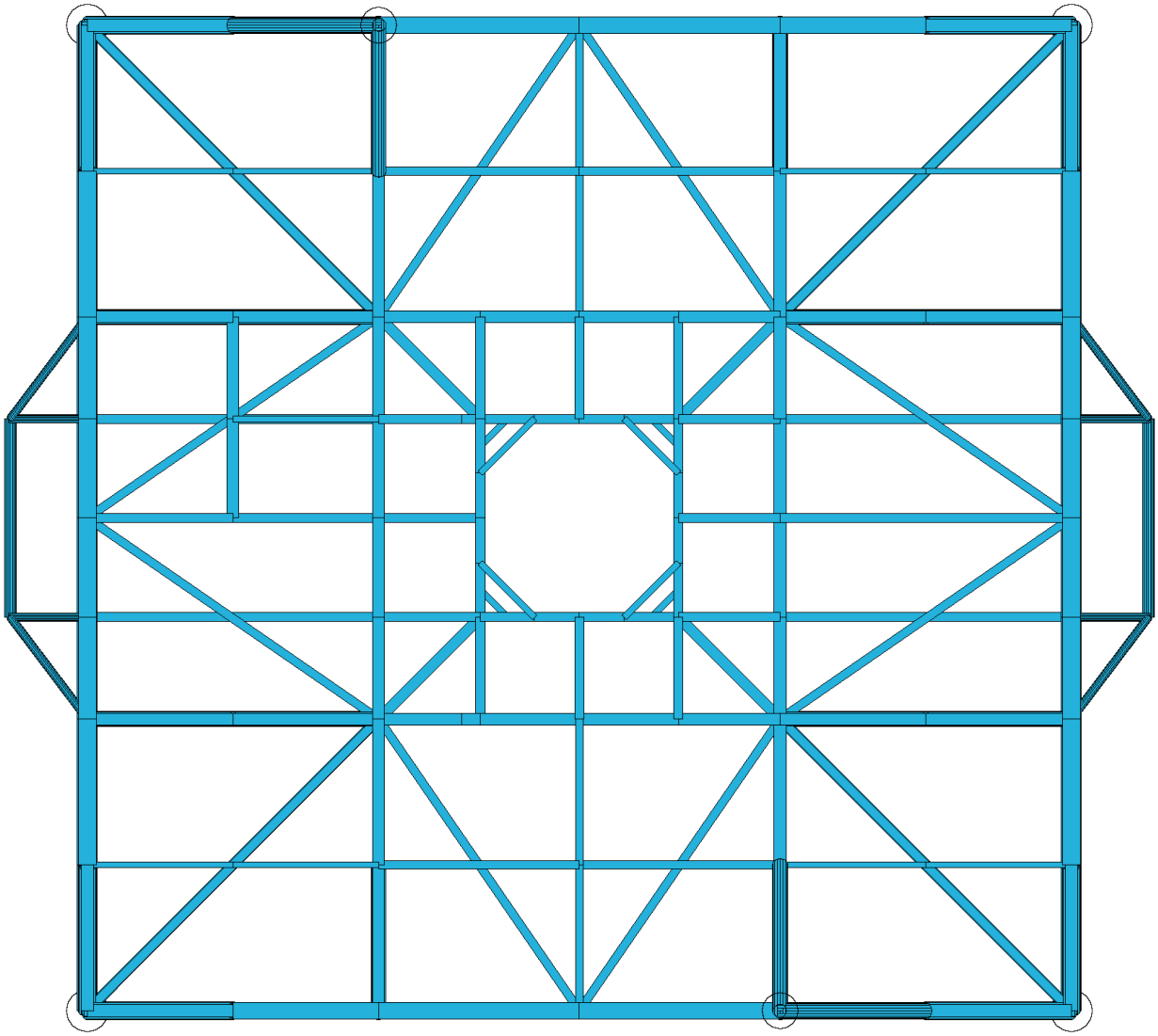
OTEC - Full Production Phase





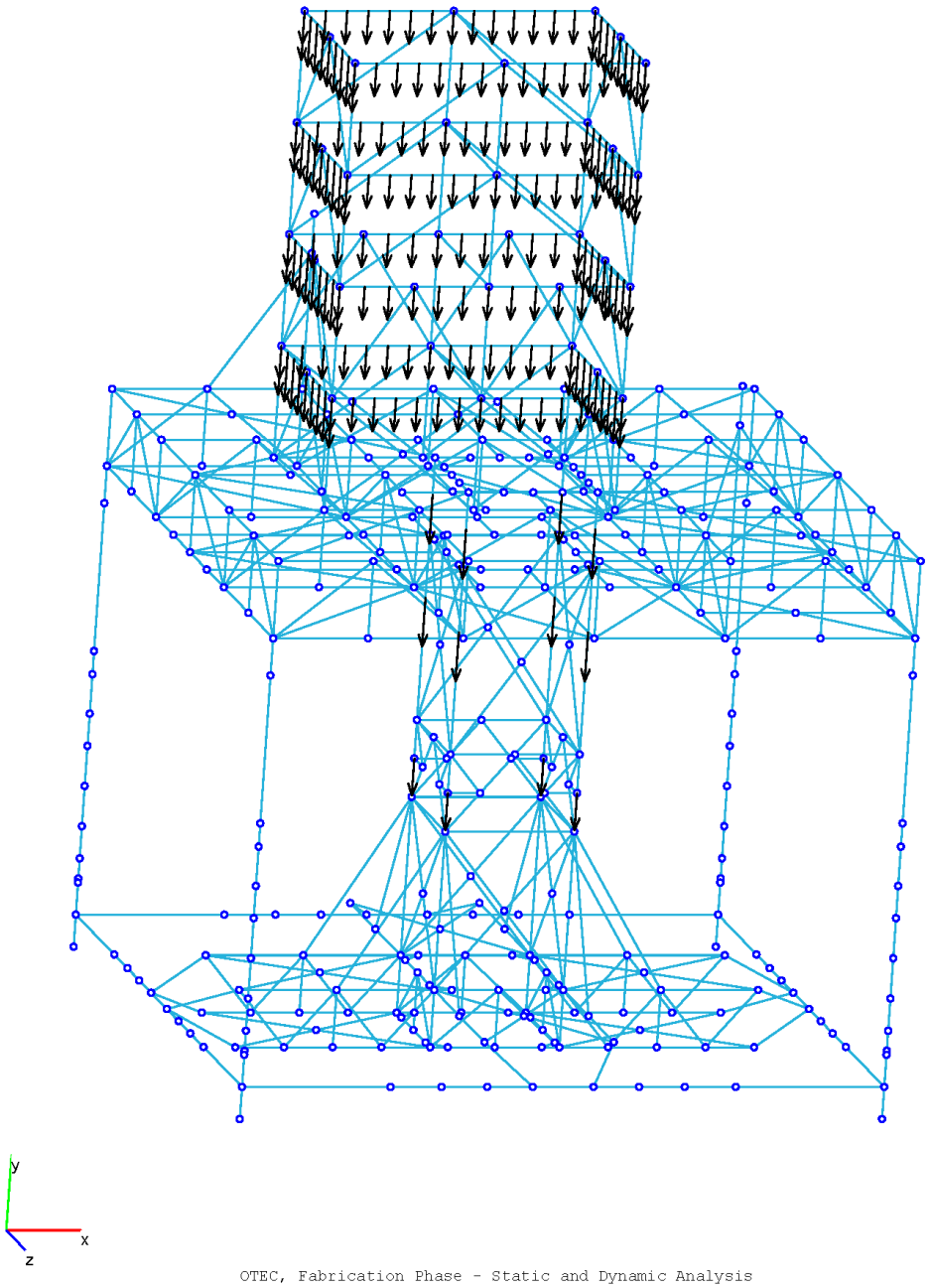
Remora Connections at Deck

OTEC - Full Production Phase

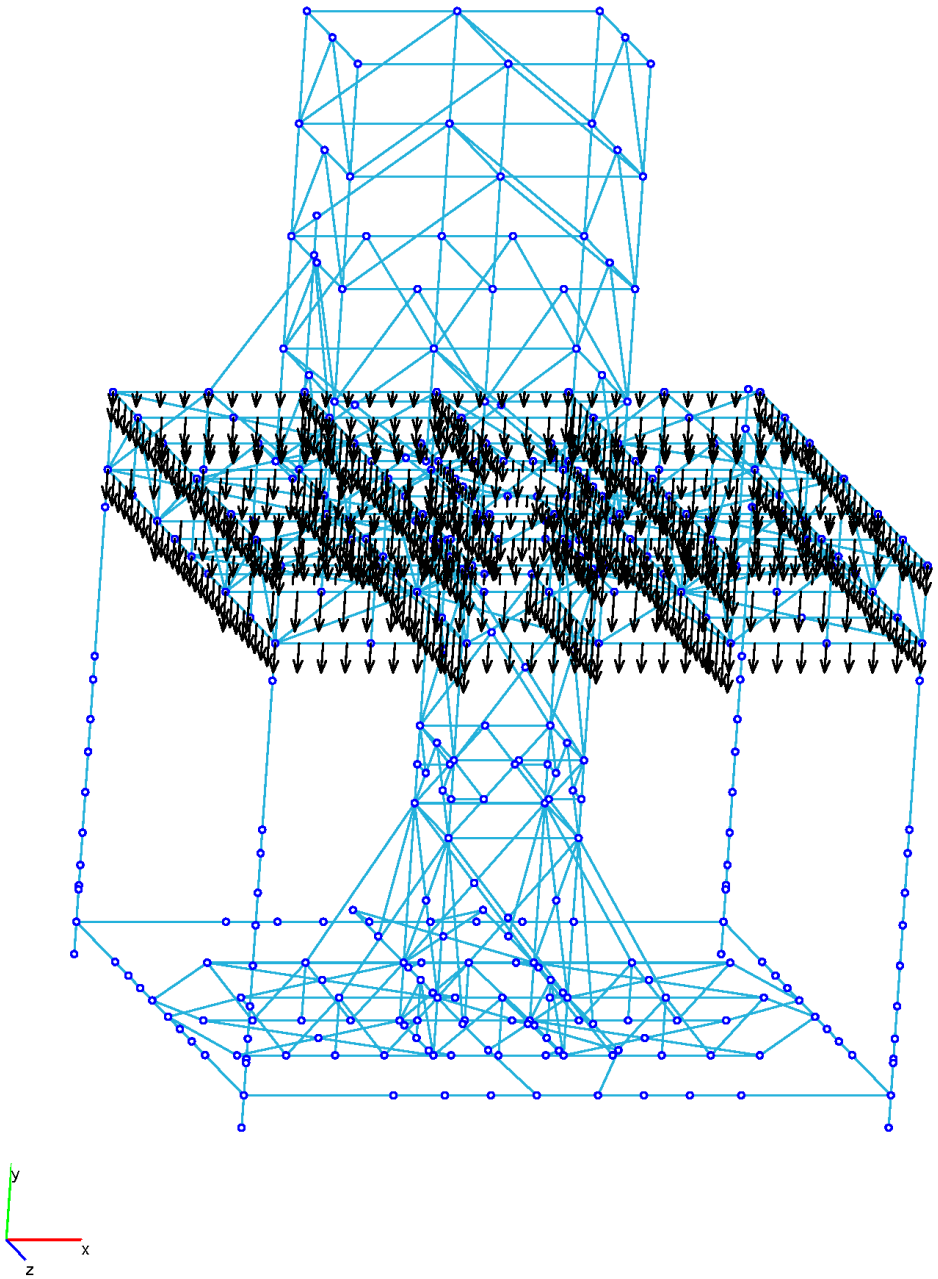


Remora Connections at Deck

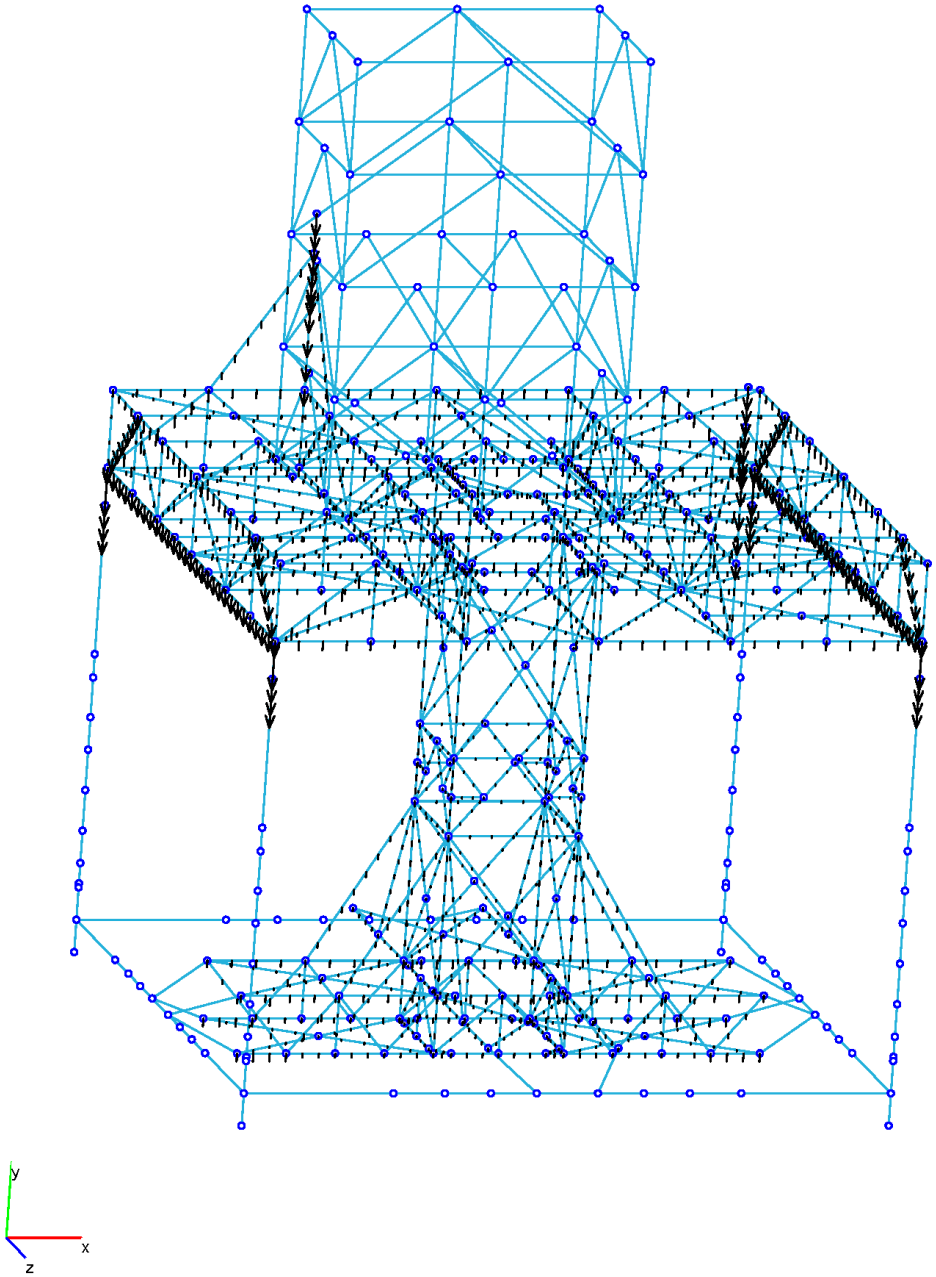
Tower Loads



Topside Equipments - Uniformly Distributed

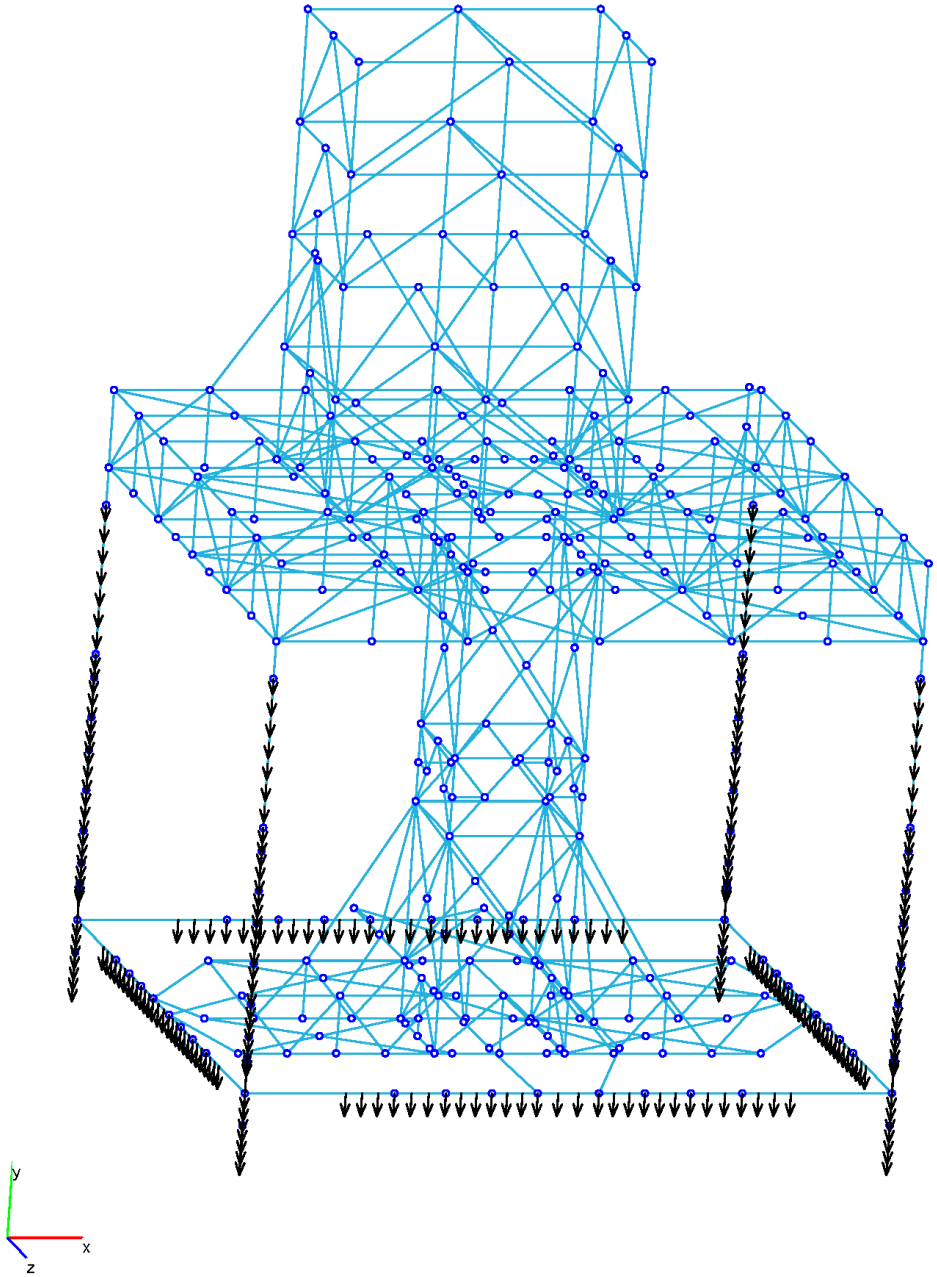


Dead Load

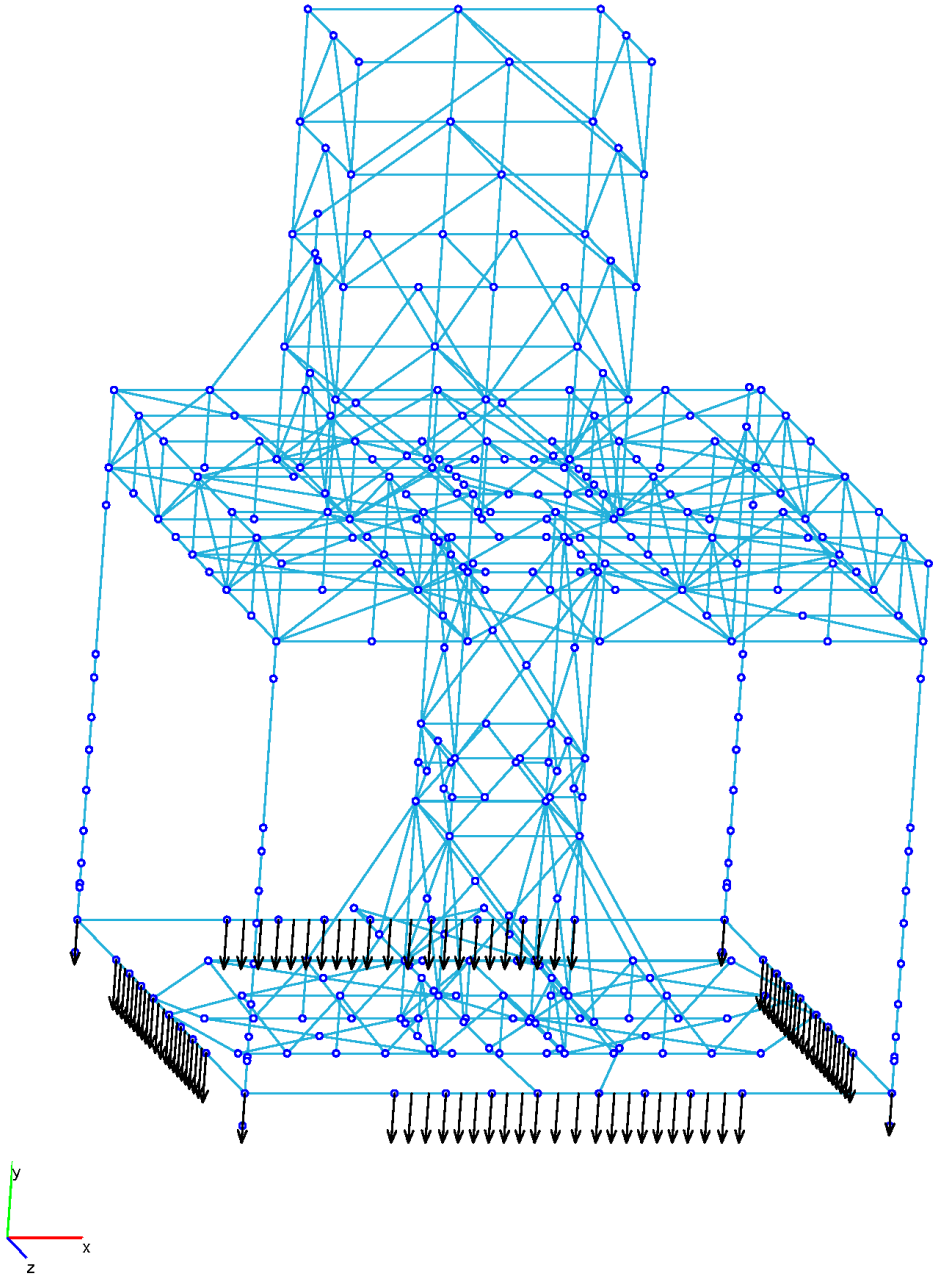


OTEC, Fabrication Phase - Static and Dynamic Analysis

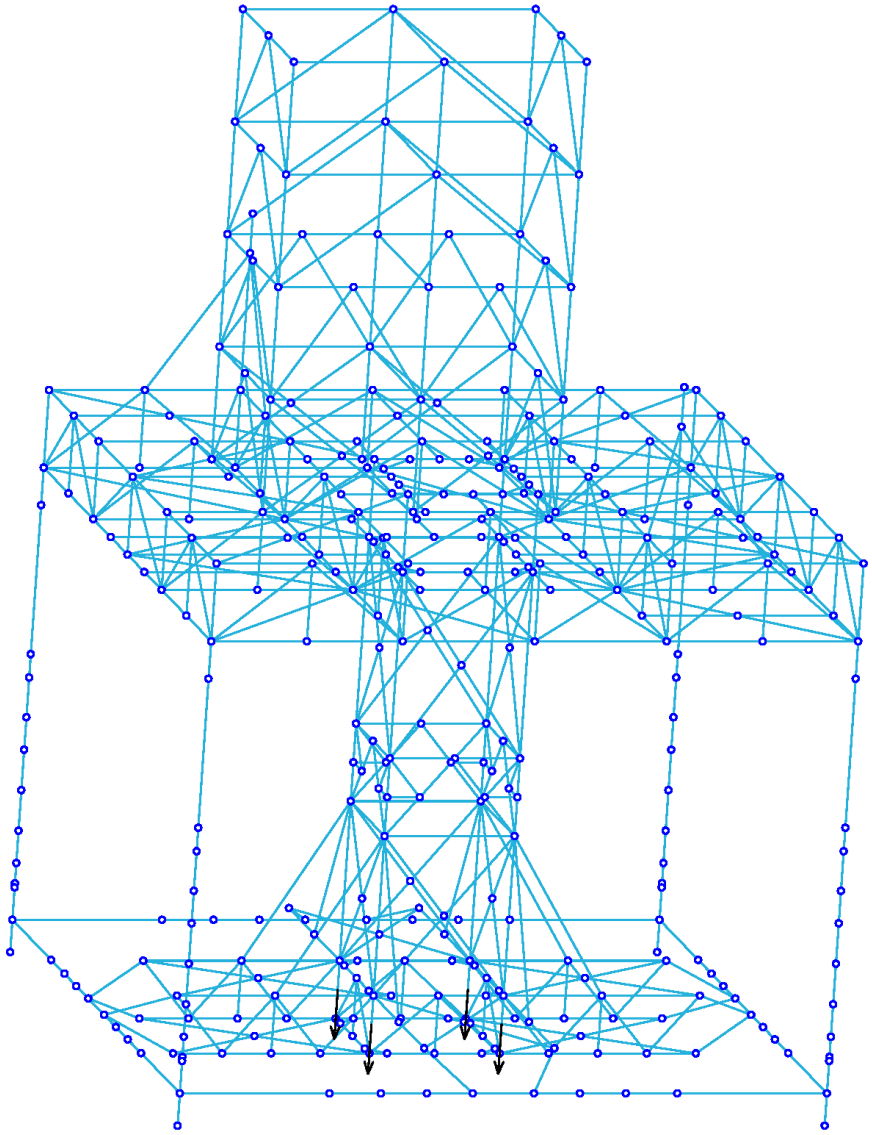
Hull Dead Load



Ballast Loads

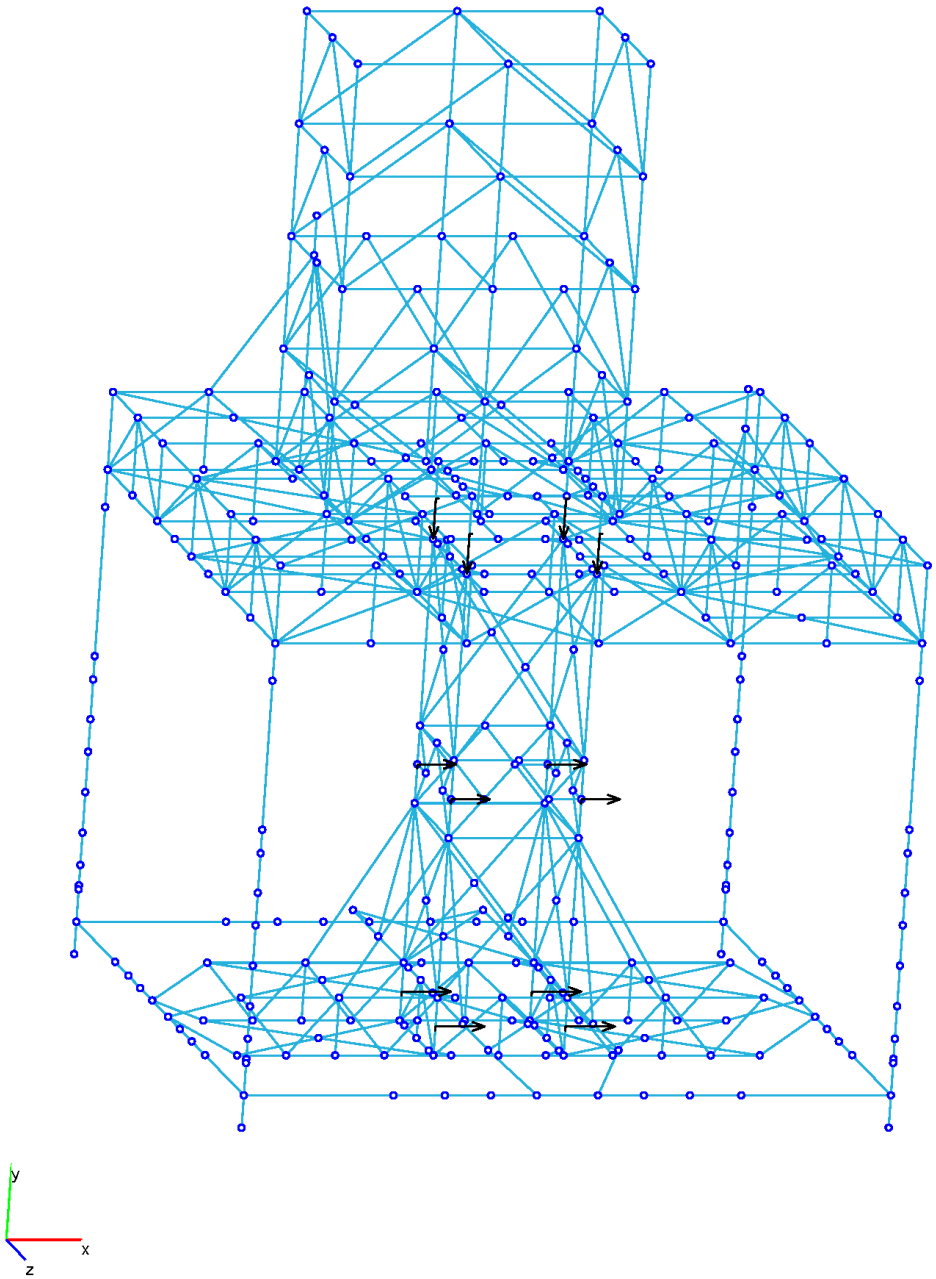


CWP and Mooring Loads

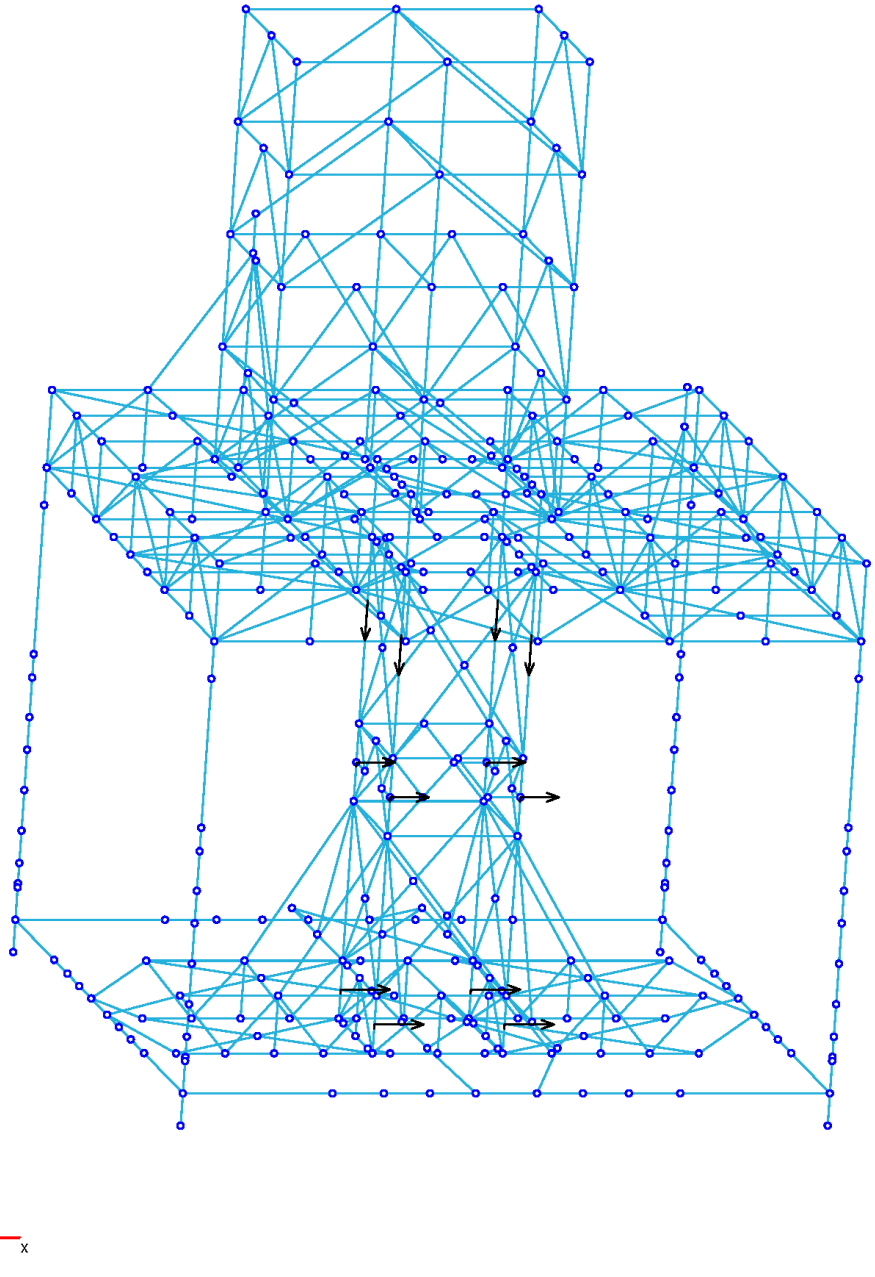


OTEC, Fabrication Phase - Static and Dynamic Analysis

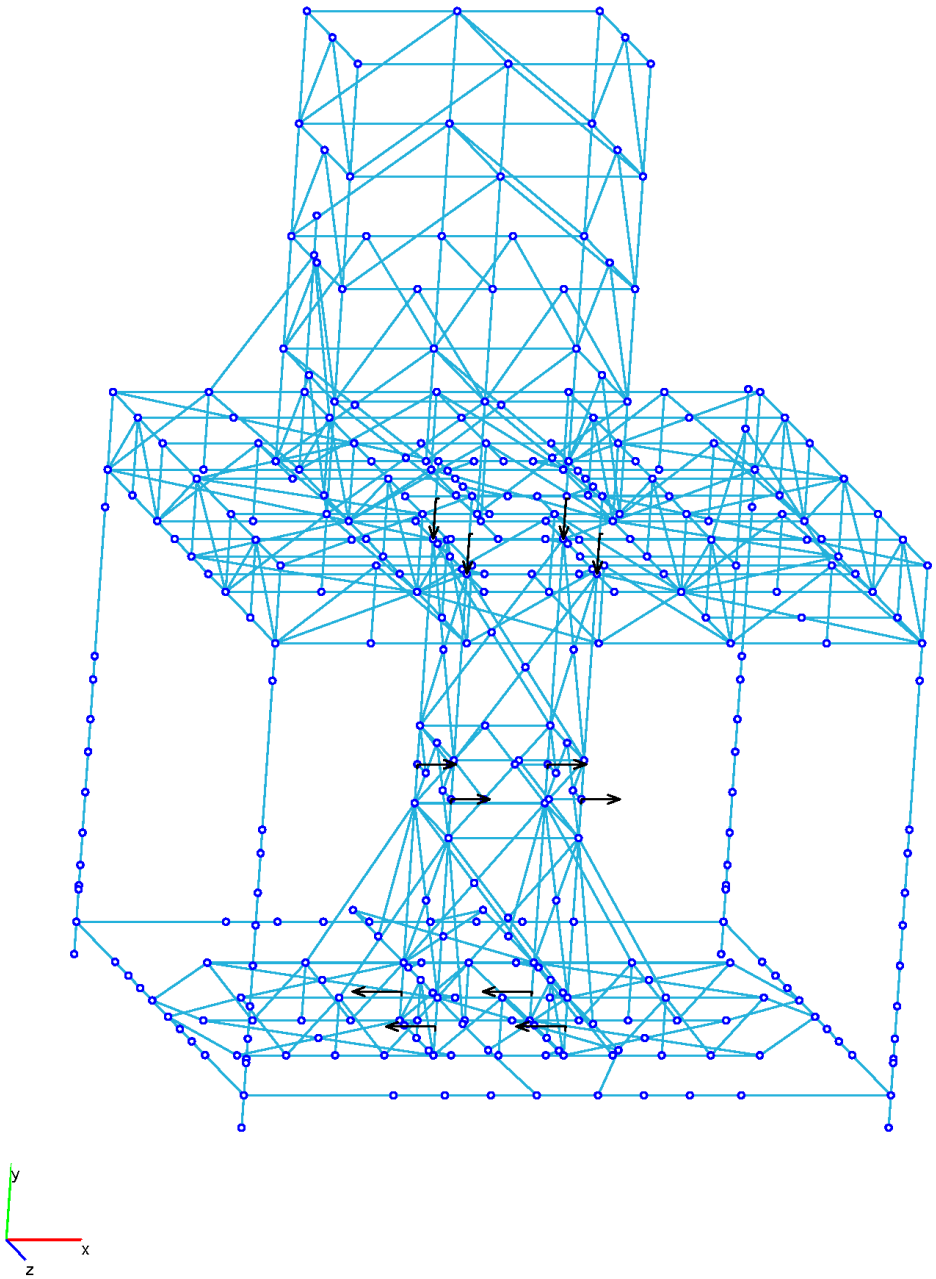
Gripper Loads - Case1: CWP Engaged by Upper Gripper only



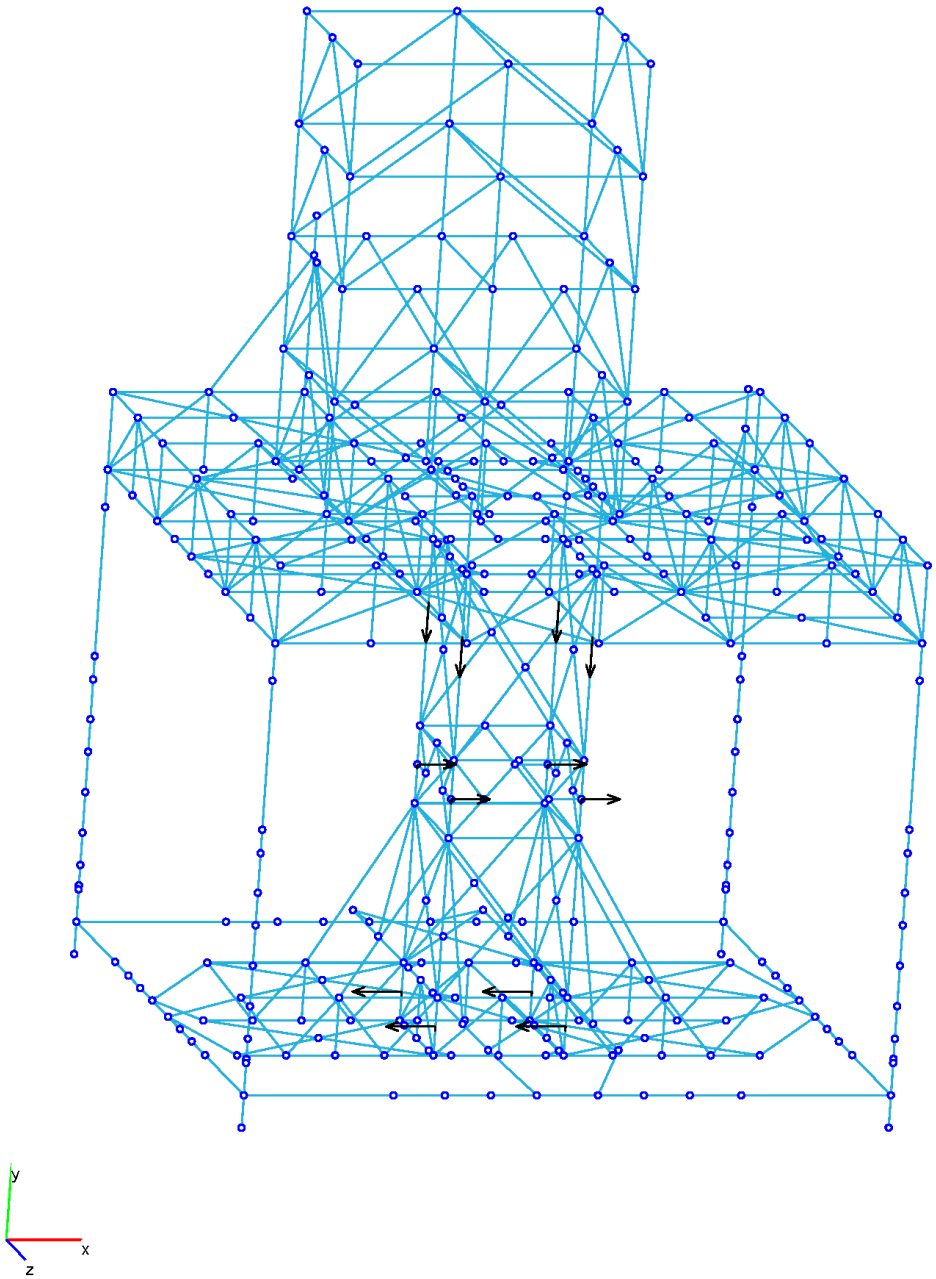
Gripper Loads - Case2: CWP Engaged by Lower Gripper only



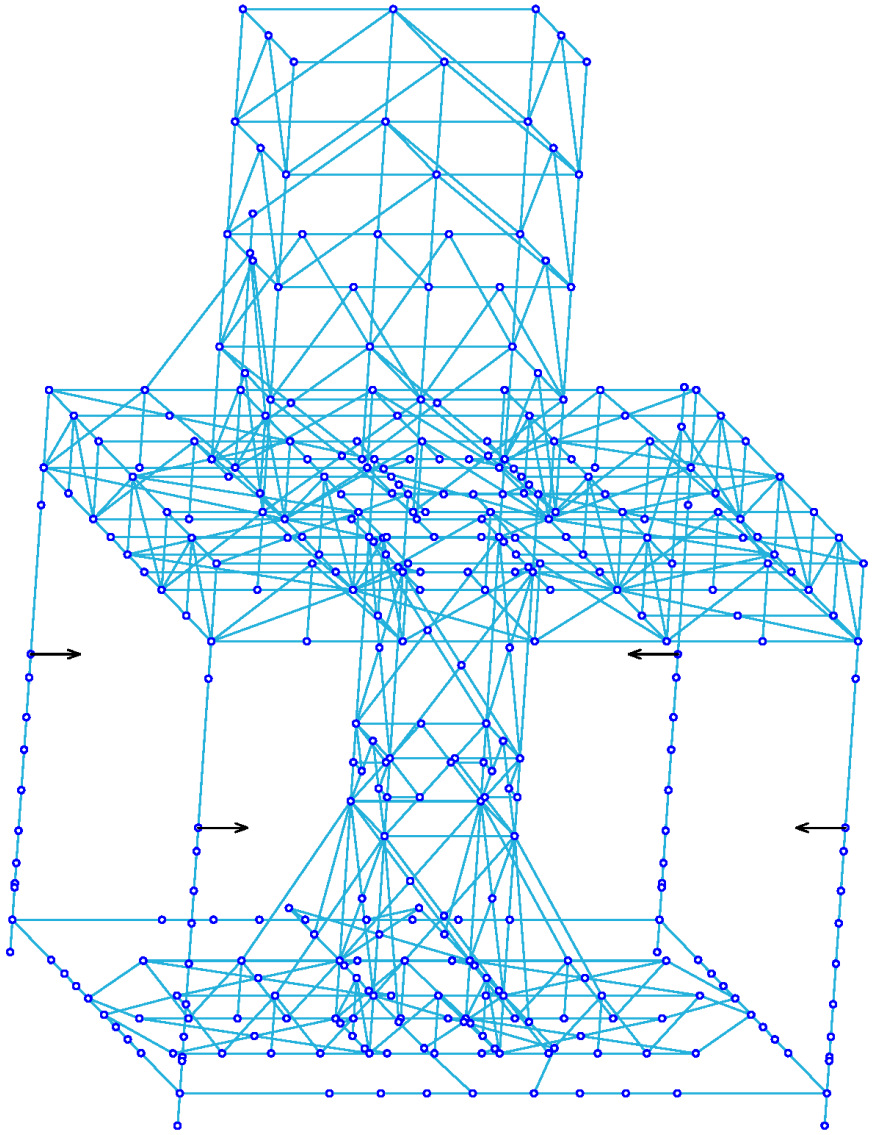
Gripper Loads - Case3: CWP Engaged by Upper Gripper only



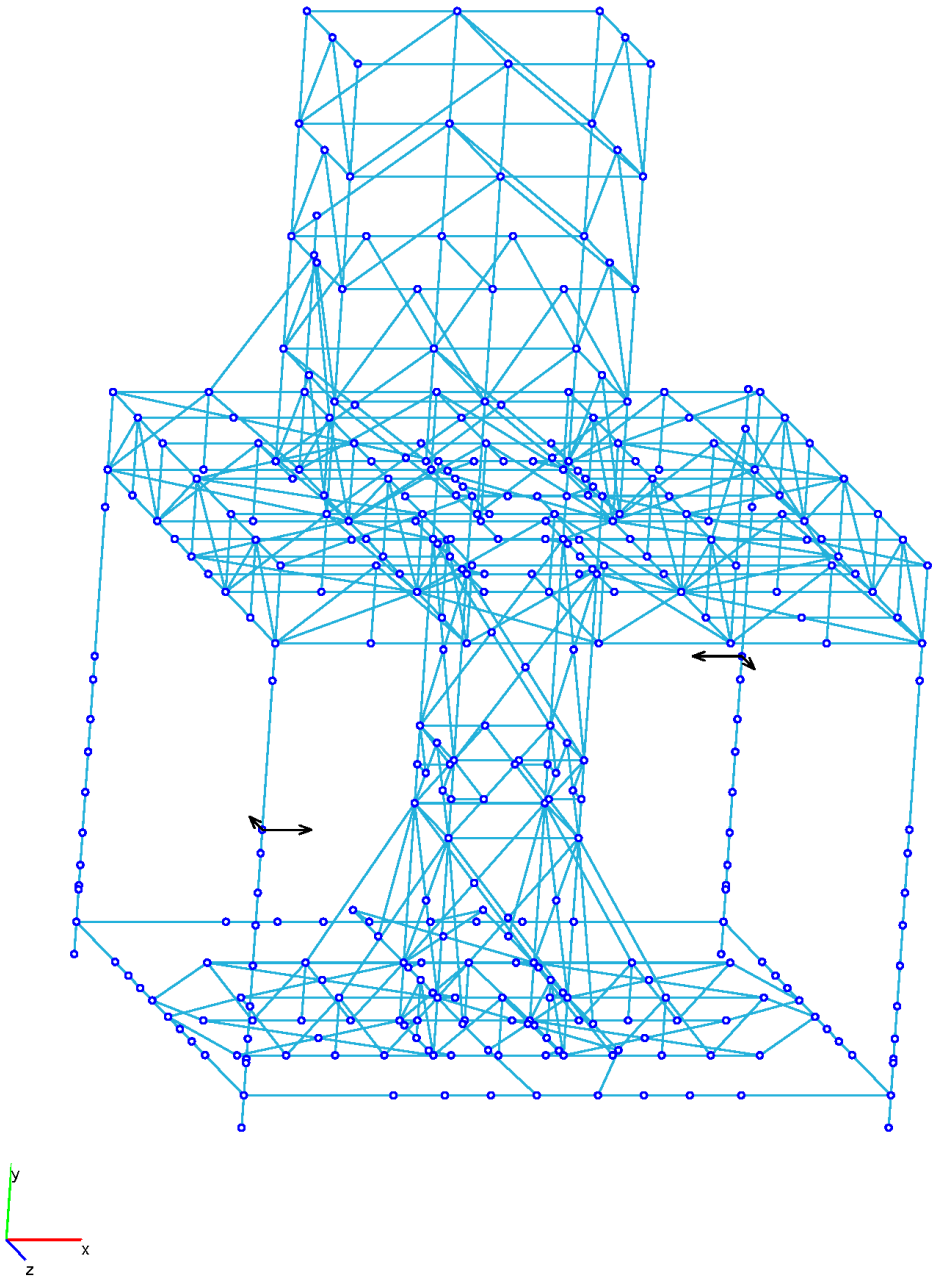
Gripper Loads - Case4: CWP Engaged by Lower Gripper only



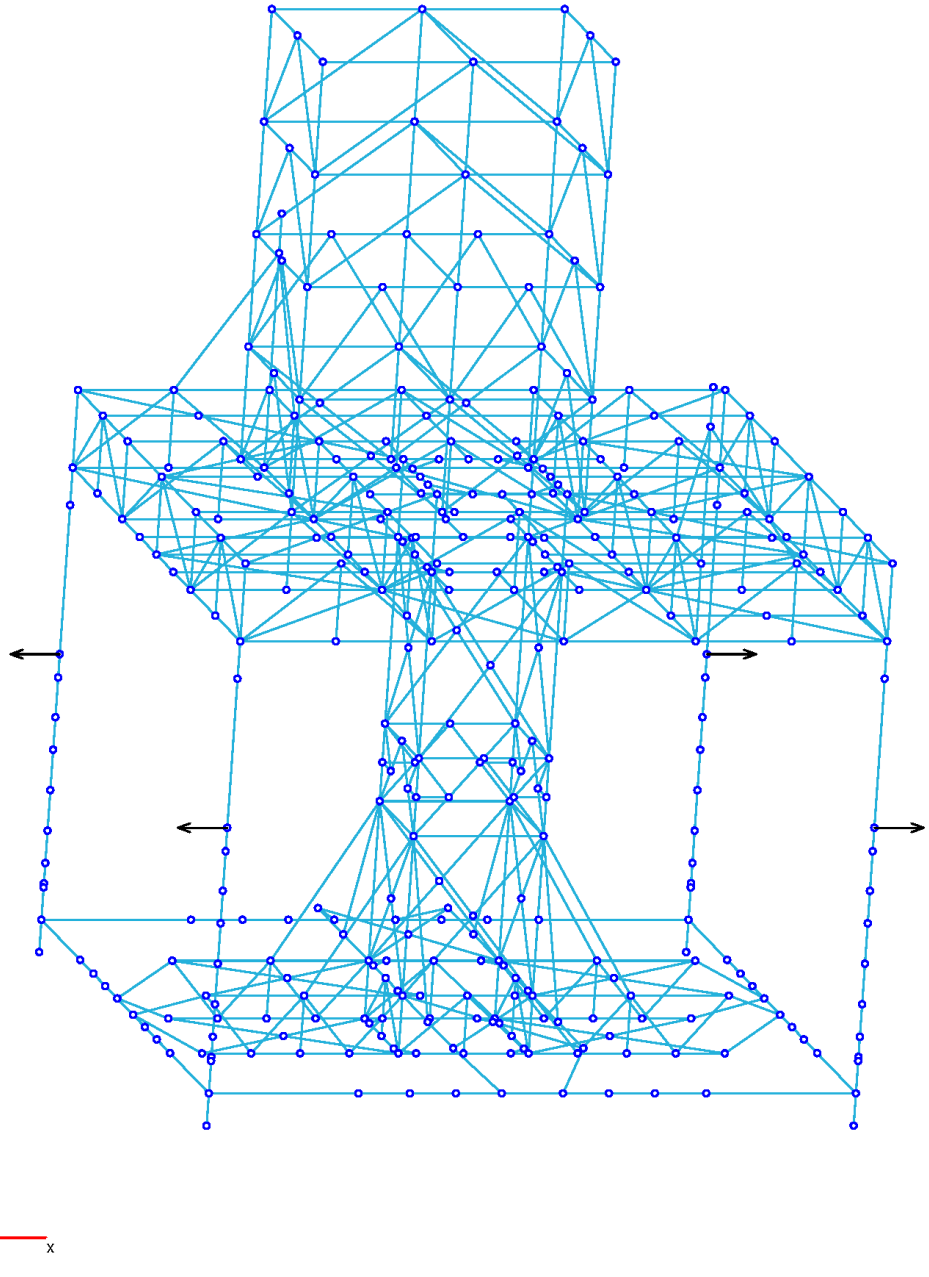
Squeeze Loads @ 0 Deg Heading



Squeeze Loads @ 45 Deg Heading

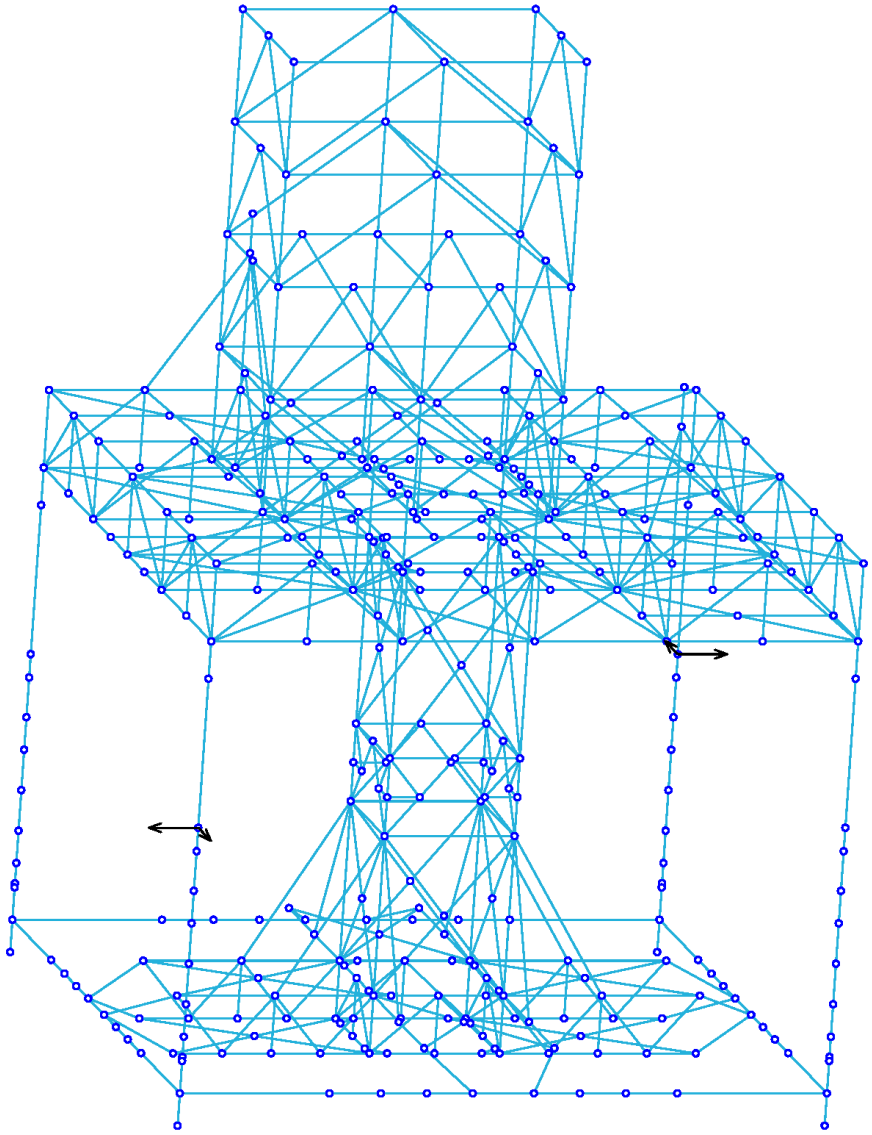


Pry Loads @ 0 Deg Heading



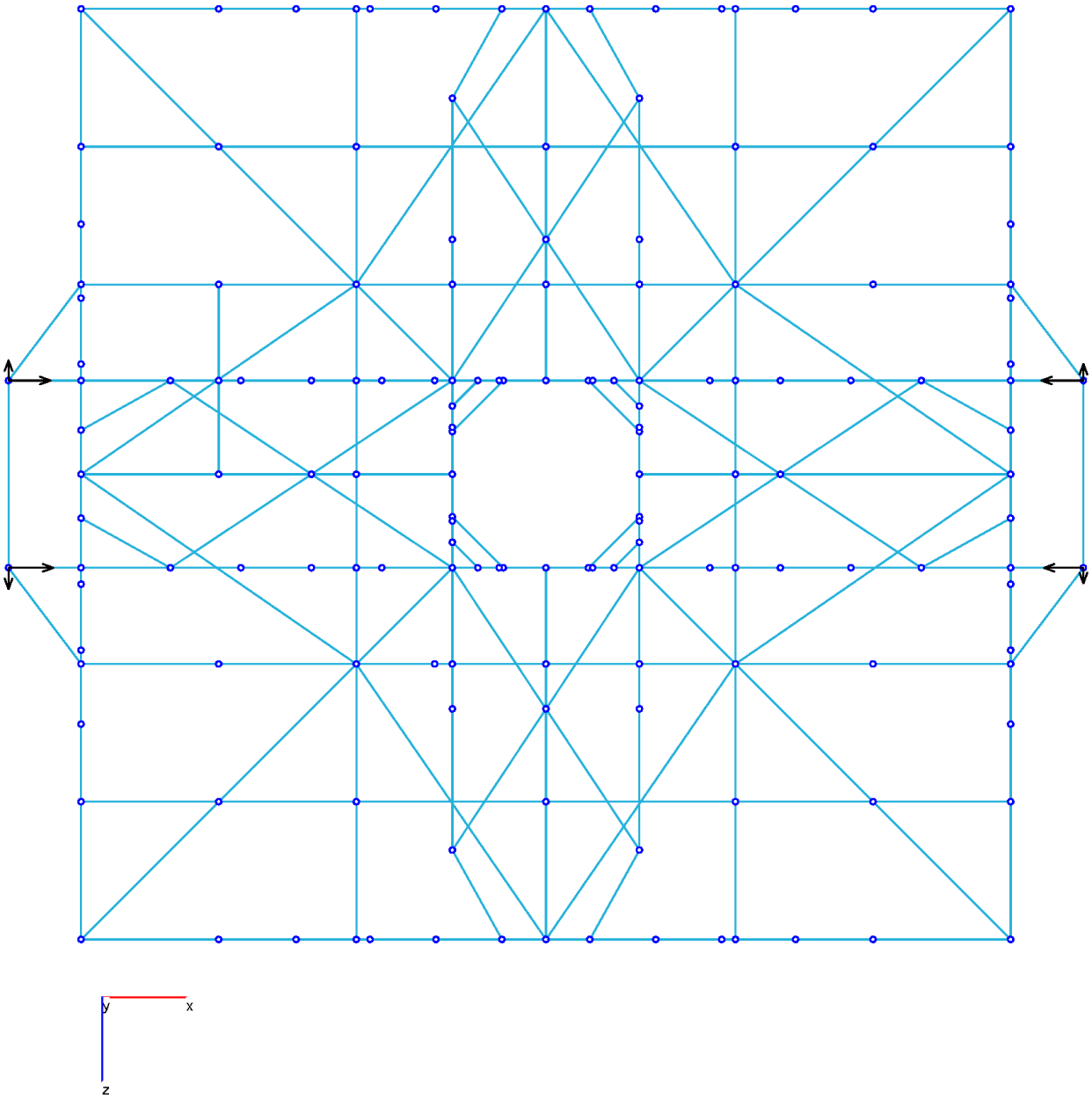
OTEC, Fabrication Phase - Static and Dynamic Analysis

Pry Loads @ 45 Deg Heading



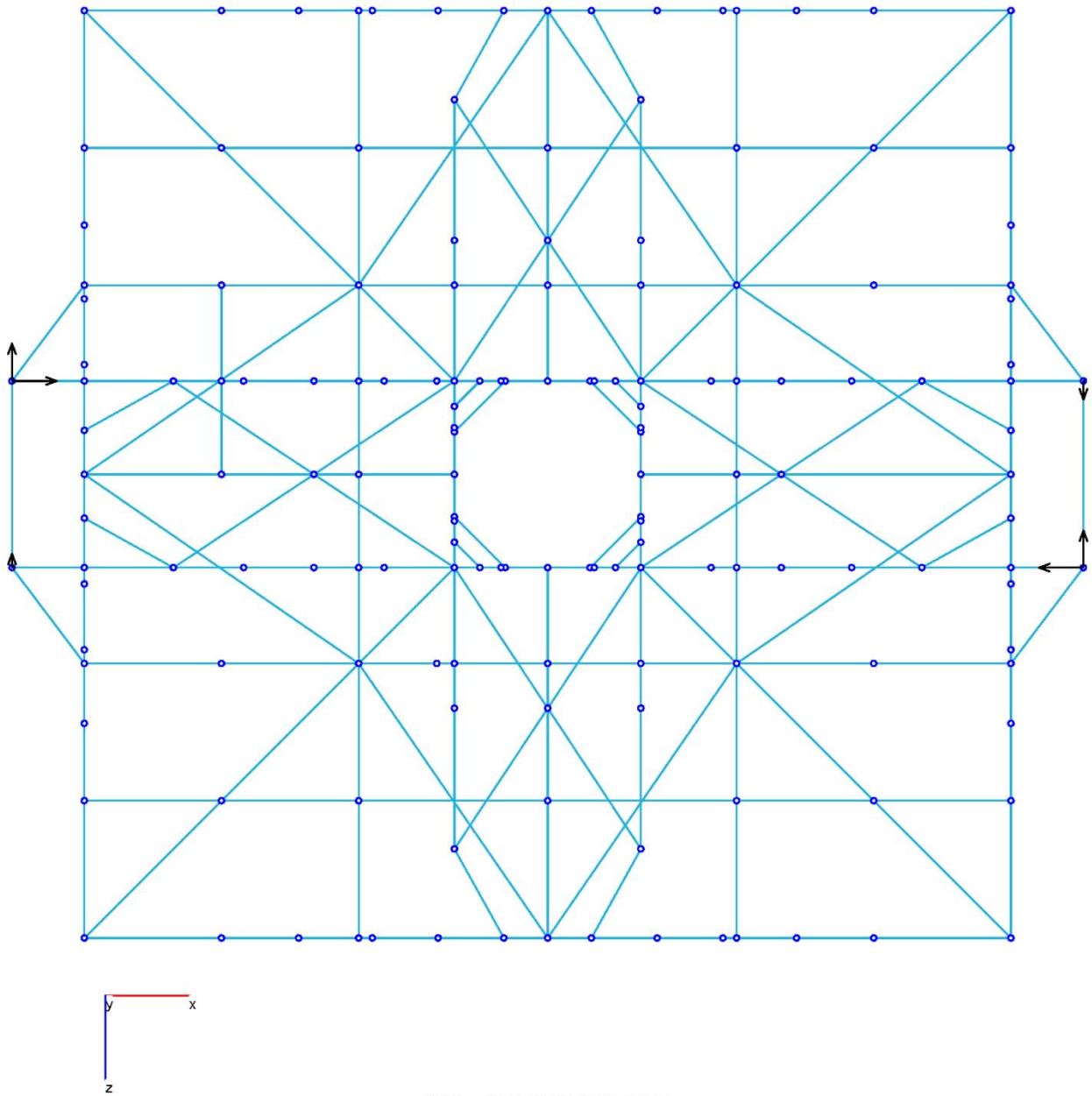
OTEC, Fabrication Phase - Static and Dynamic Analysis

Remora Loads - Case1 - 0 Deg Heading

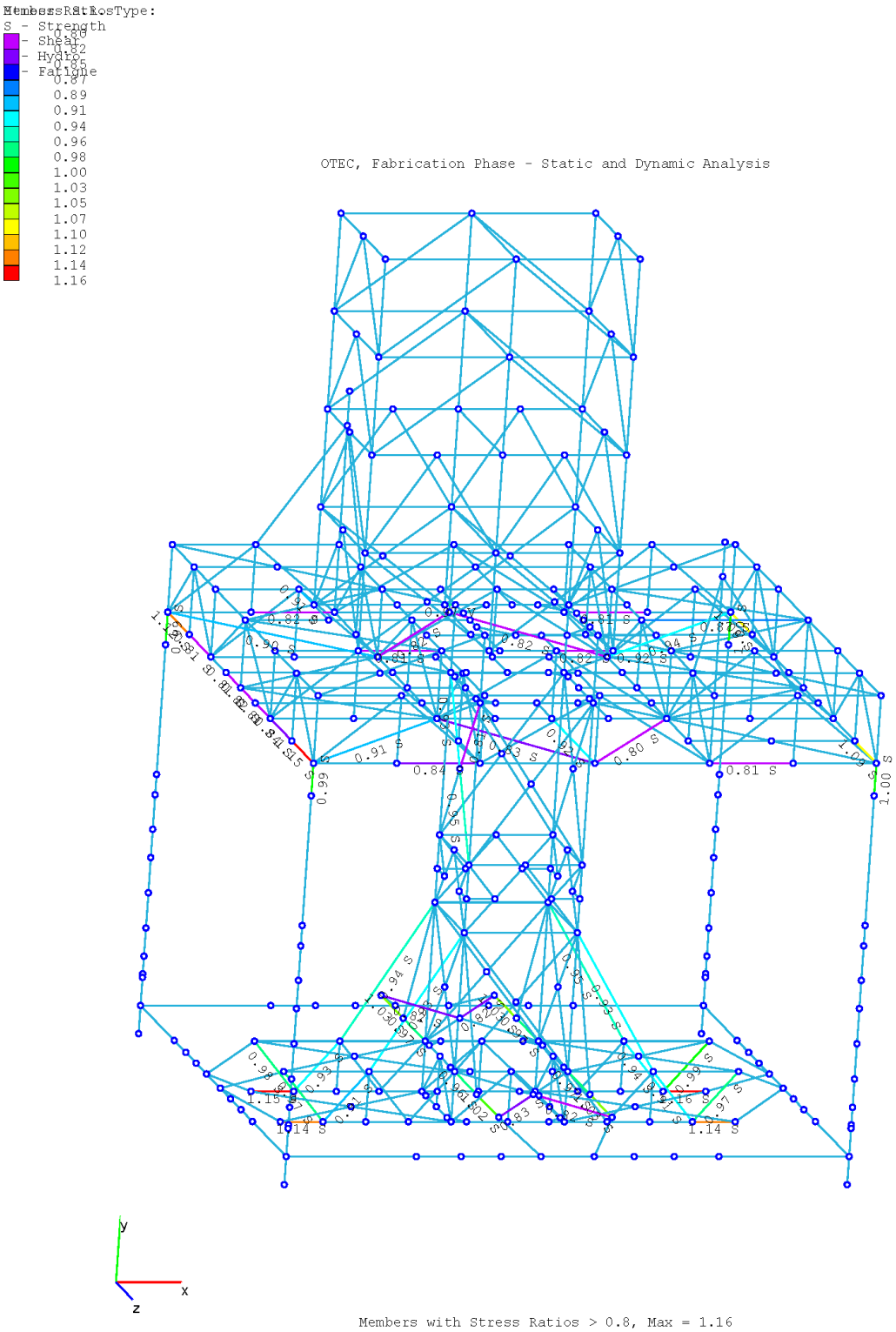


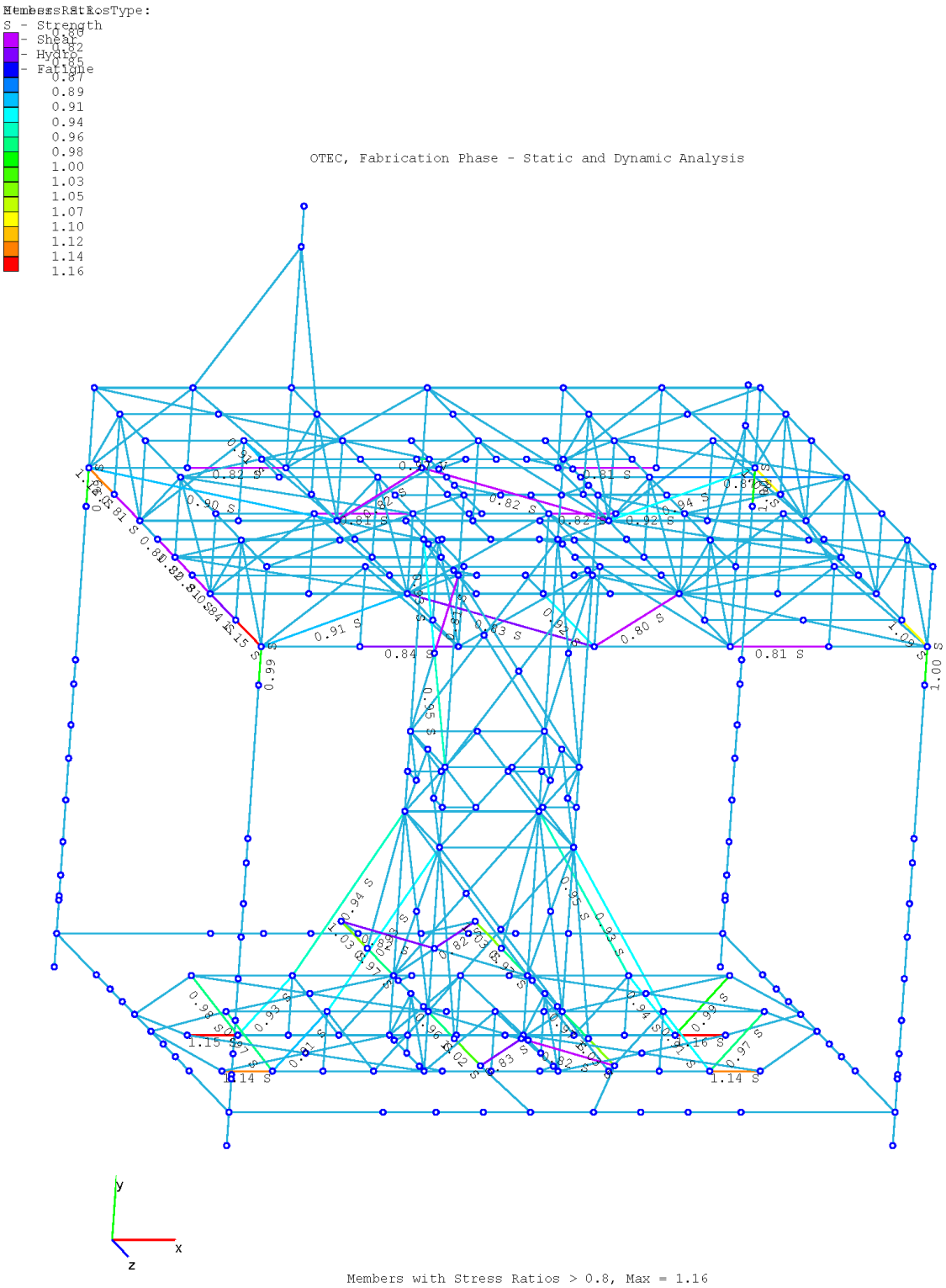
OTEC - Full Production Phase

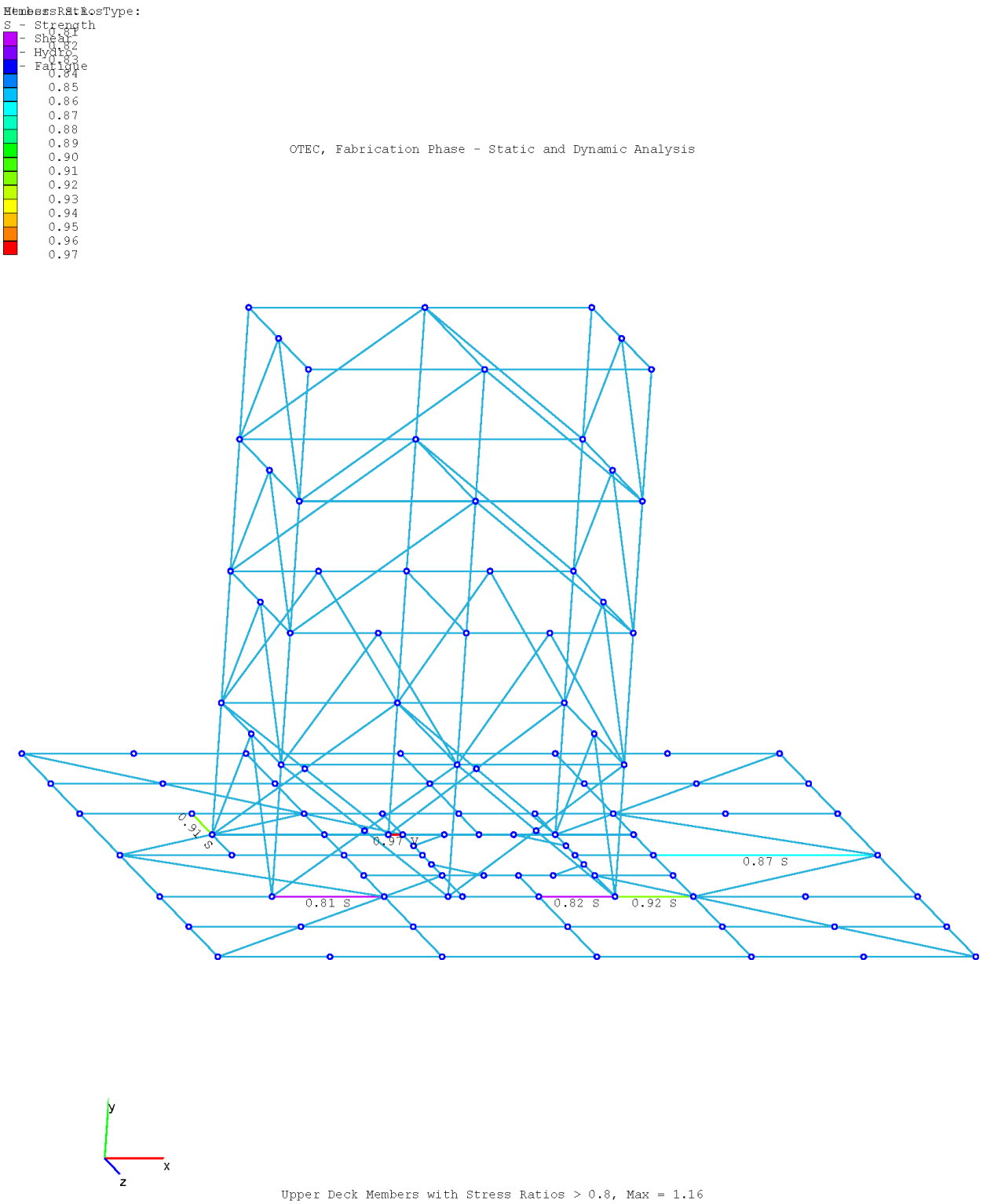
Remora Loads - Case1 - 45 Deg Heading

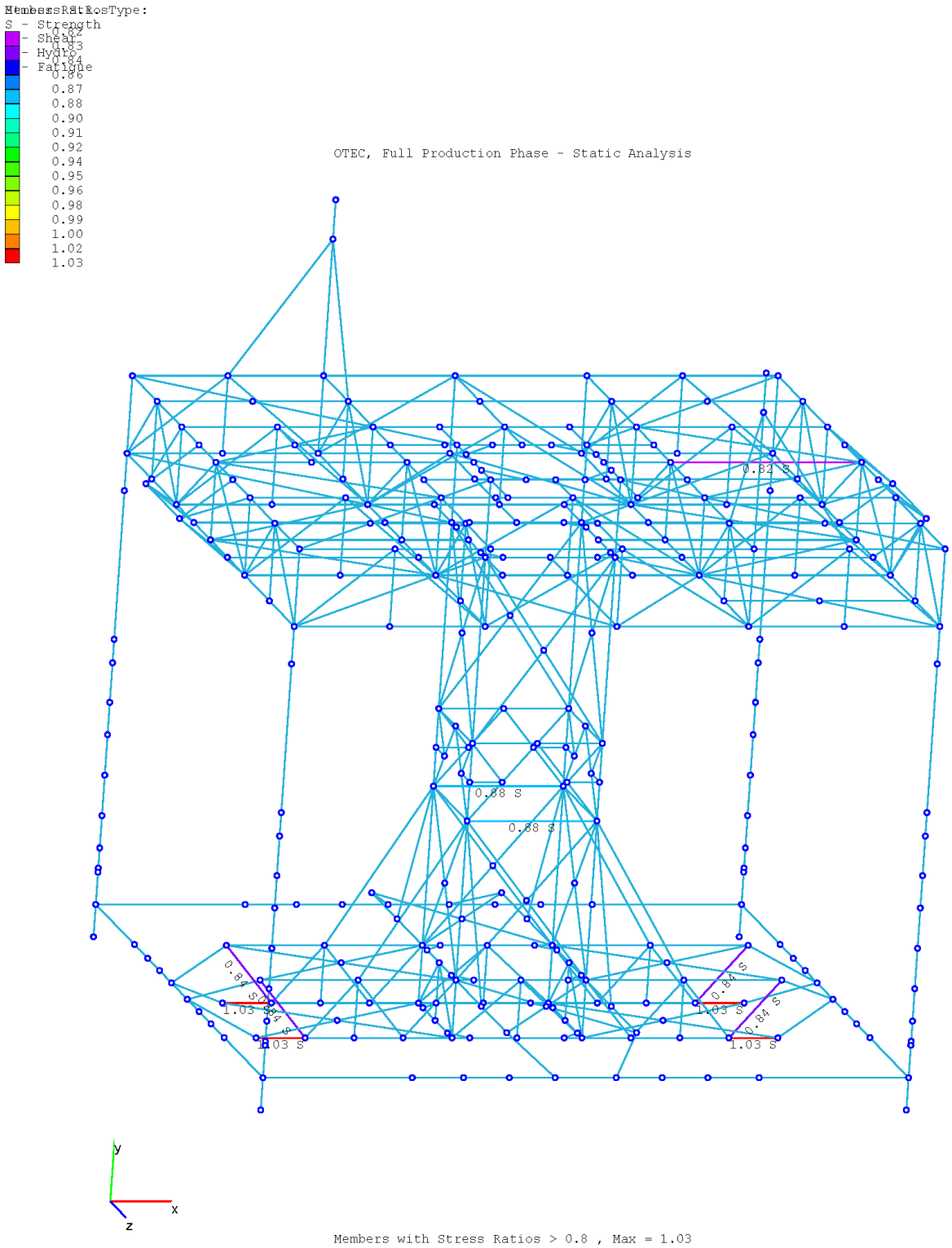


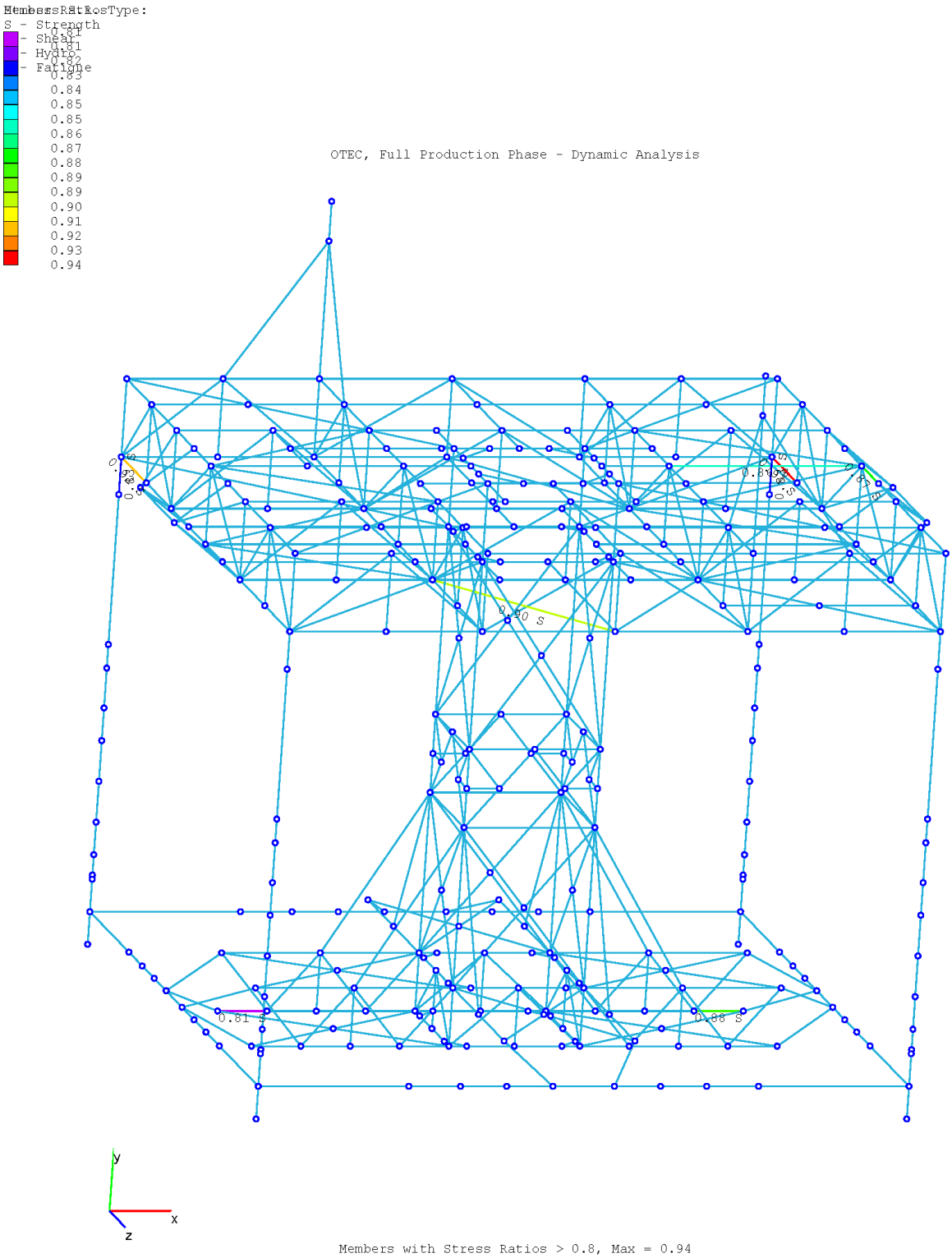
OTEC - Full Production Phase


Members Ratios Type:
S - Strength
- Shear
- Hydro
- Fatigue
0.80
0.82
0.85
0.87
0.89
0.91
0.94
0.96
0.98
1.00
1.03
1.05
1.07
1.10
1.12
1.14
1.16
OTEC, Fabrication Phase - Static and Dynamic Analysis
y
x
z
Members with Stress Ratios > 0.8, Max = 1.16


Members Ratios Type:
S - Strength
- Shear
- Hydro
- Fatigue
0.80
0.82
0.85
0.87
0.89
0.91
0.94
0.96
0.98
1.00
1.03
1.05
1.07
1.10
1.12
1.14
1.16
OTEC, Fabrication Phase - Static and Dynamic Analysis
y
x
z
Members with Stress Ratios > 0.8, Max = 1.16


MembersRatiosType:
S - Strength
- Shear
- Hydro
- Fatigue
0.81
0.82
0.83
0.84
0.85
0.86
0.87
0.88
0.89
0.90
0.91
0.92
0.93
0.94
0.95
0.96
0.97
OTEC, Fabrication Phase - Static and Dynamic Analysis
0.91 S
0.97 H
0.87 S
0.81 S
0.82 S
0.92 S
y
x
z
Upper Deck Members with Stress Ratios > 0.8, Max = 1.16


Members Ratios Type:
S - Strength
- Shear
- Hydro
- Fatigue
0.82
0.83
0.84
0.86
0.87
0.88
0.90
0.91
0.92
0.94
0.95
0.96
0.98
0.99
1.00
1.02
1.03
OTEC, Full Production Phase - Static Analysis
0.82 S
0.88 S
0.88 S
0.84 S
1.03 S
0.84 S
1.03 S
0.84 S
1.03 S
0.84 S
1.03 S
y
x
z
Members with Stress Ratios > 0.8 , Max = 1.03


Members Ratios Type:
S - Strength
- Shear
- Hydro
- Fatigue
0.81
0.81
0.82
0.83
0.84
0.85
0.85
0.86
0.87
0.88
0.89
0.89
0.90
0.91
0.92
0.93
0.94
OTEC, Full Production Phase - Dynamic Analysis
0.90 S
0.81 S
0.88 S
y
x
z
Members with Stress Ratios > 0.8, Max = 0.94

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-7
Hull Structural Global Analysis Results
OTEC-2010-001

17 September 2010

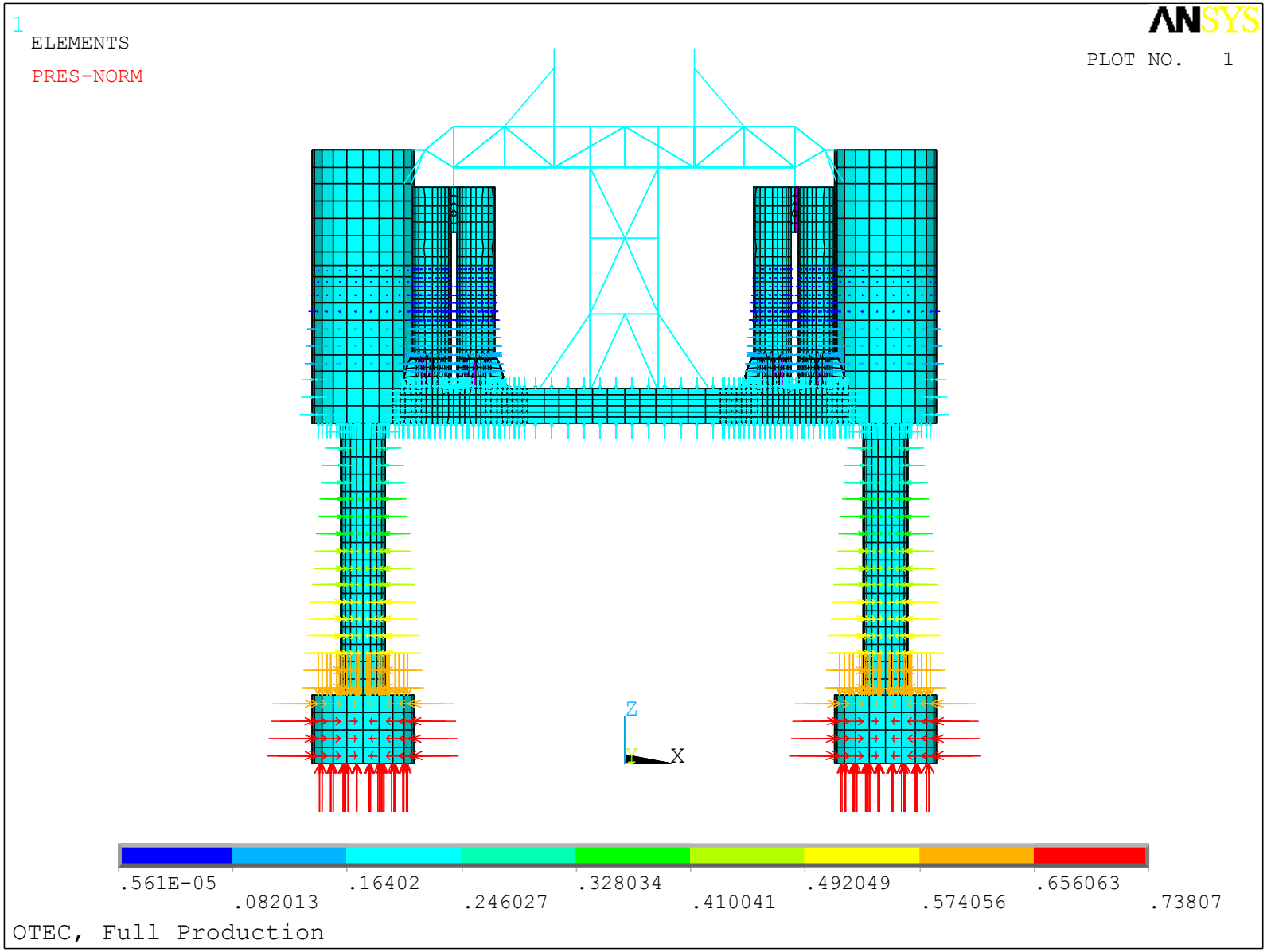
Prepared for:

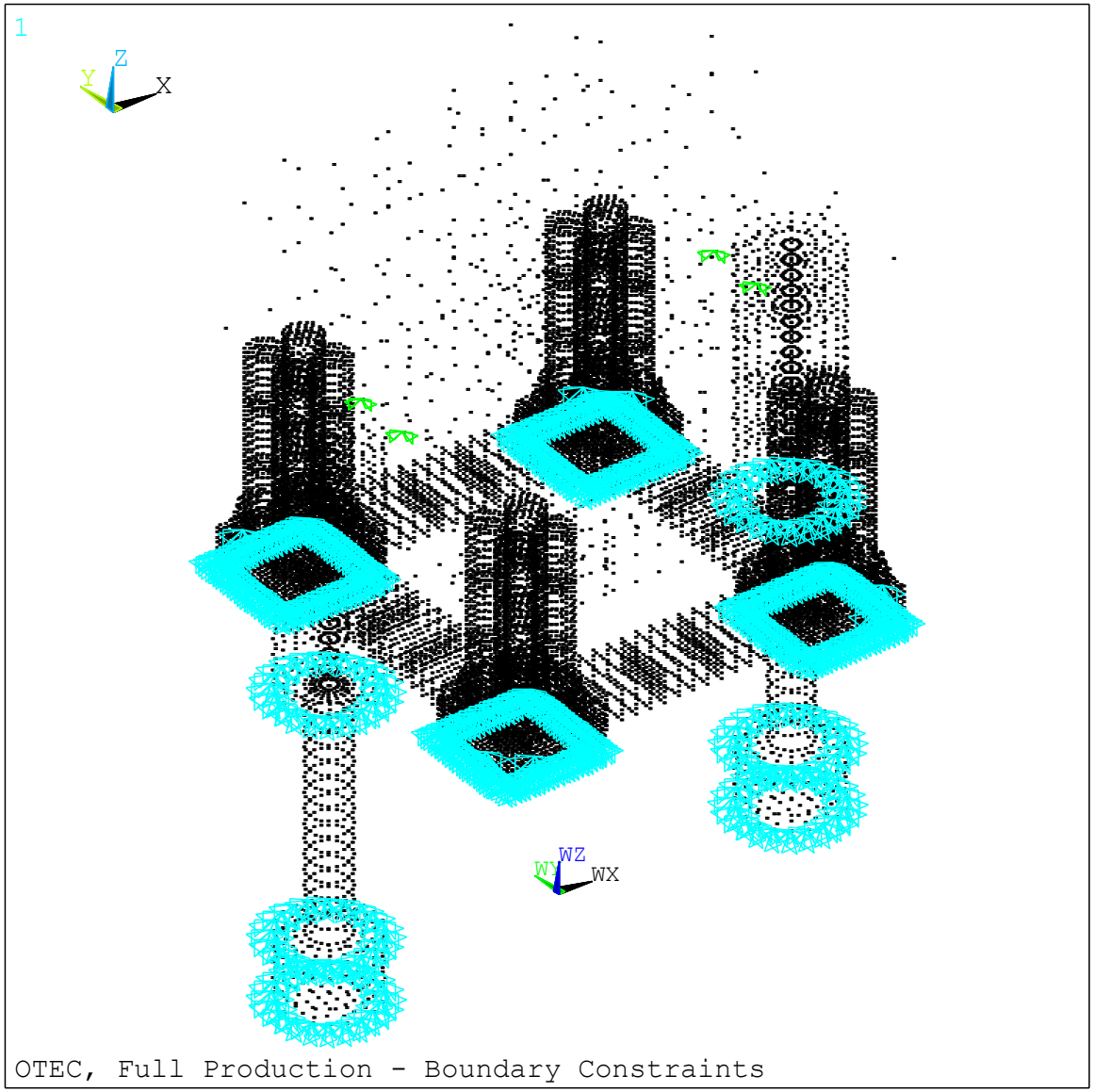
Naval Facilities Engineering Command
Naval Facilities Engineering Service Center (NFESC)
1100 23rd Avenue
Port Hueneme, CA 93043-4370
Attn: Mr. Brian Cable, Contracting Officer Representative

Prepared by:

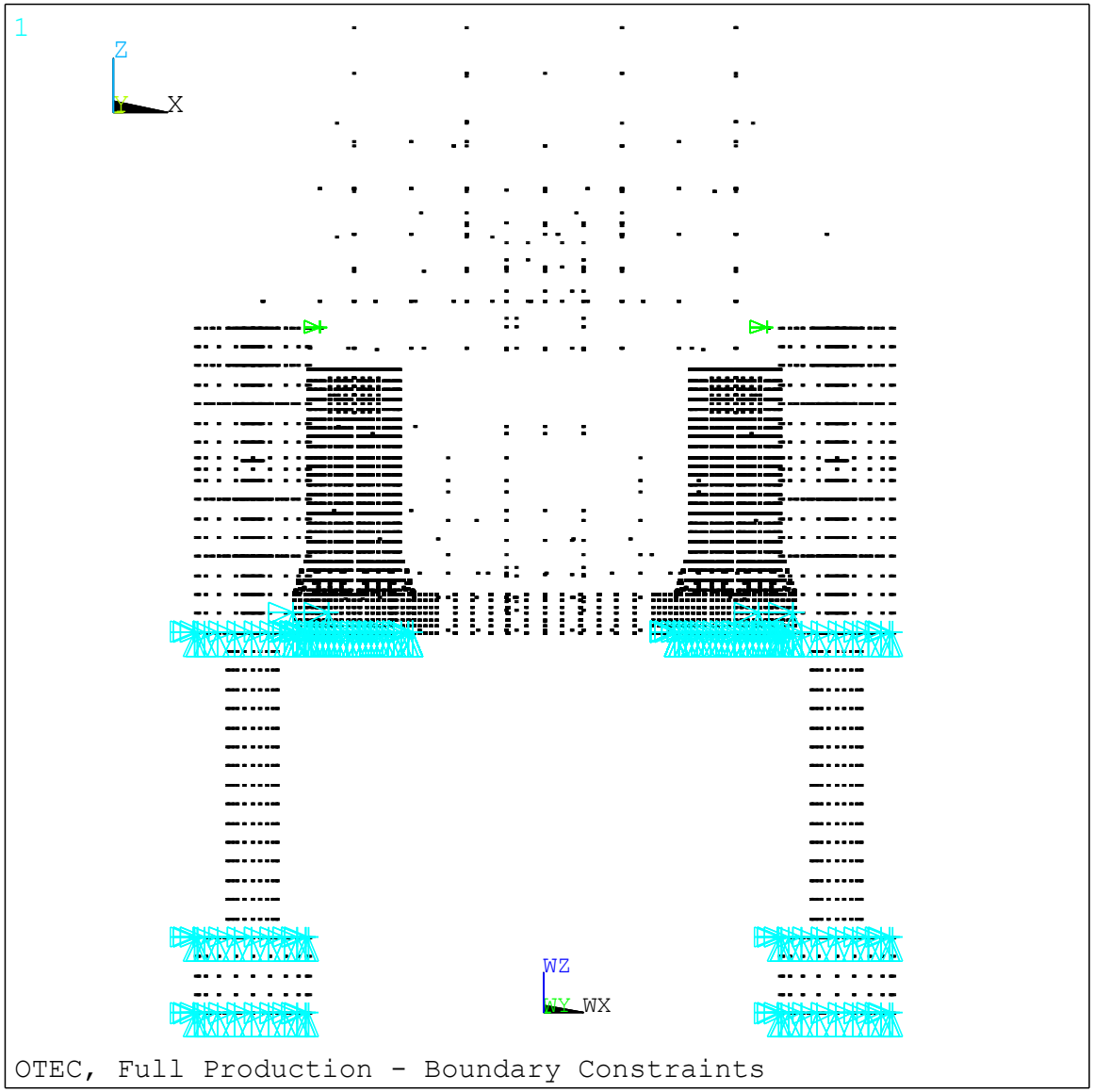
Lockheed Martin MS2
9500 Godwin Drive
Manassas, VA 20110

Distribution Statement A: Approved for public release; distribution is unlimited

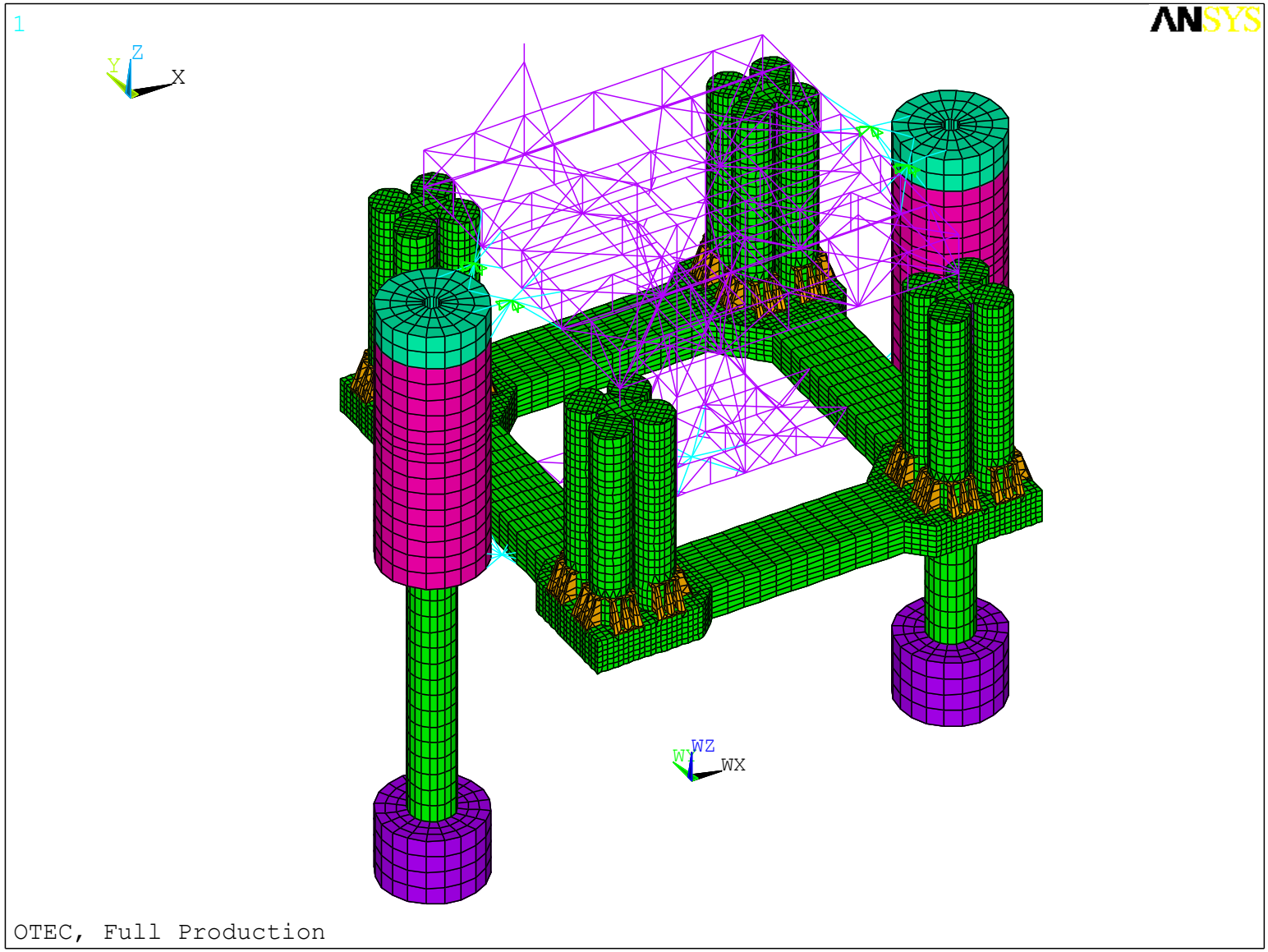

1
ELEMENTS
PRES-NORM
ANSYS
PLOT NO. 1
Z
X
.561E-05
.082013
.16402
.246027
.328034
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.73807
OTEC, Full Production

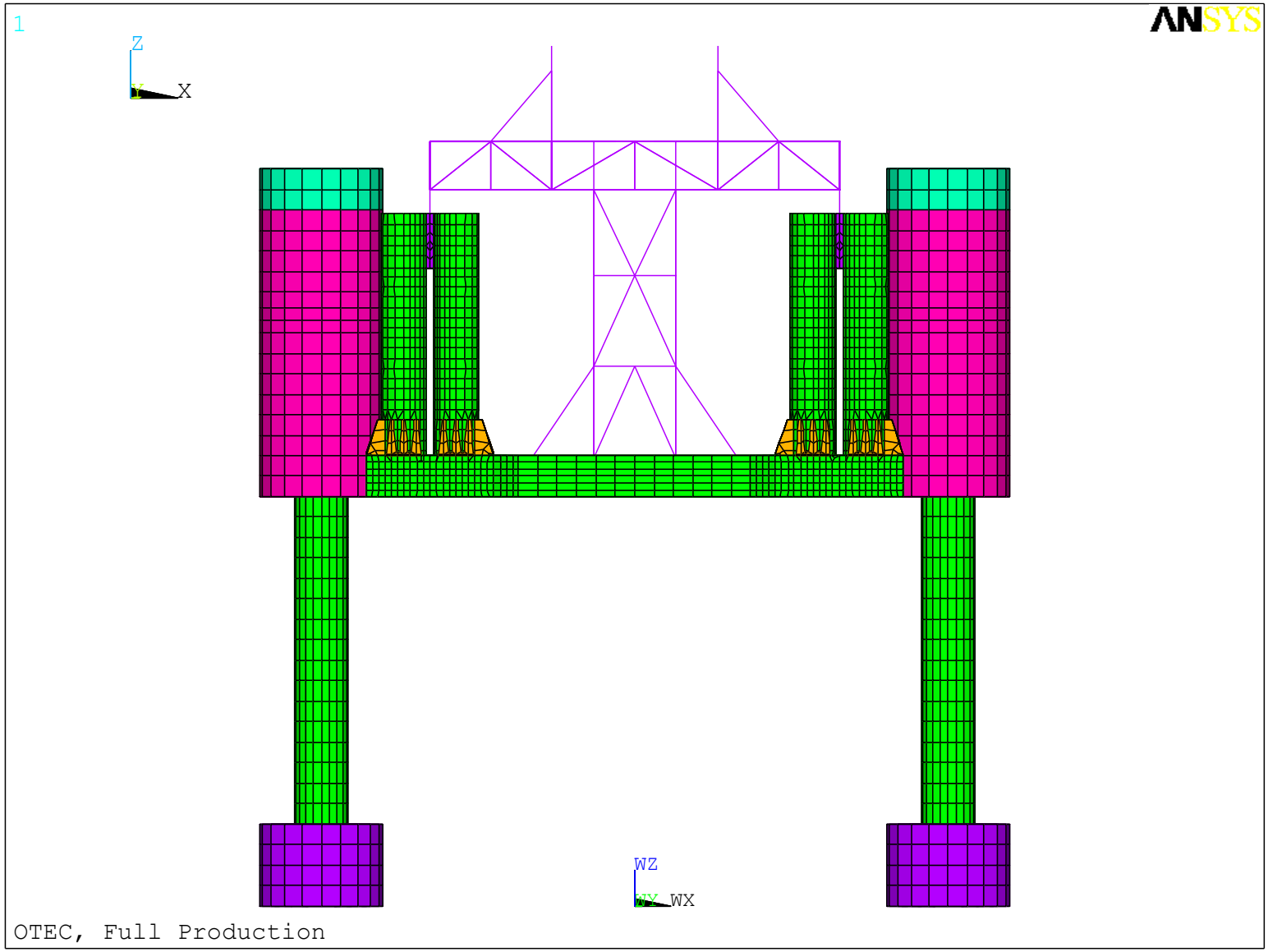


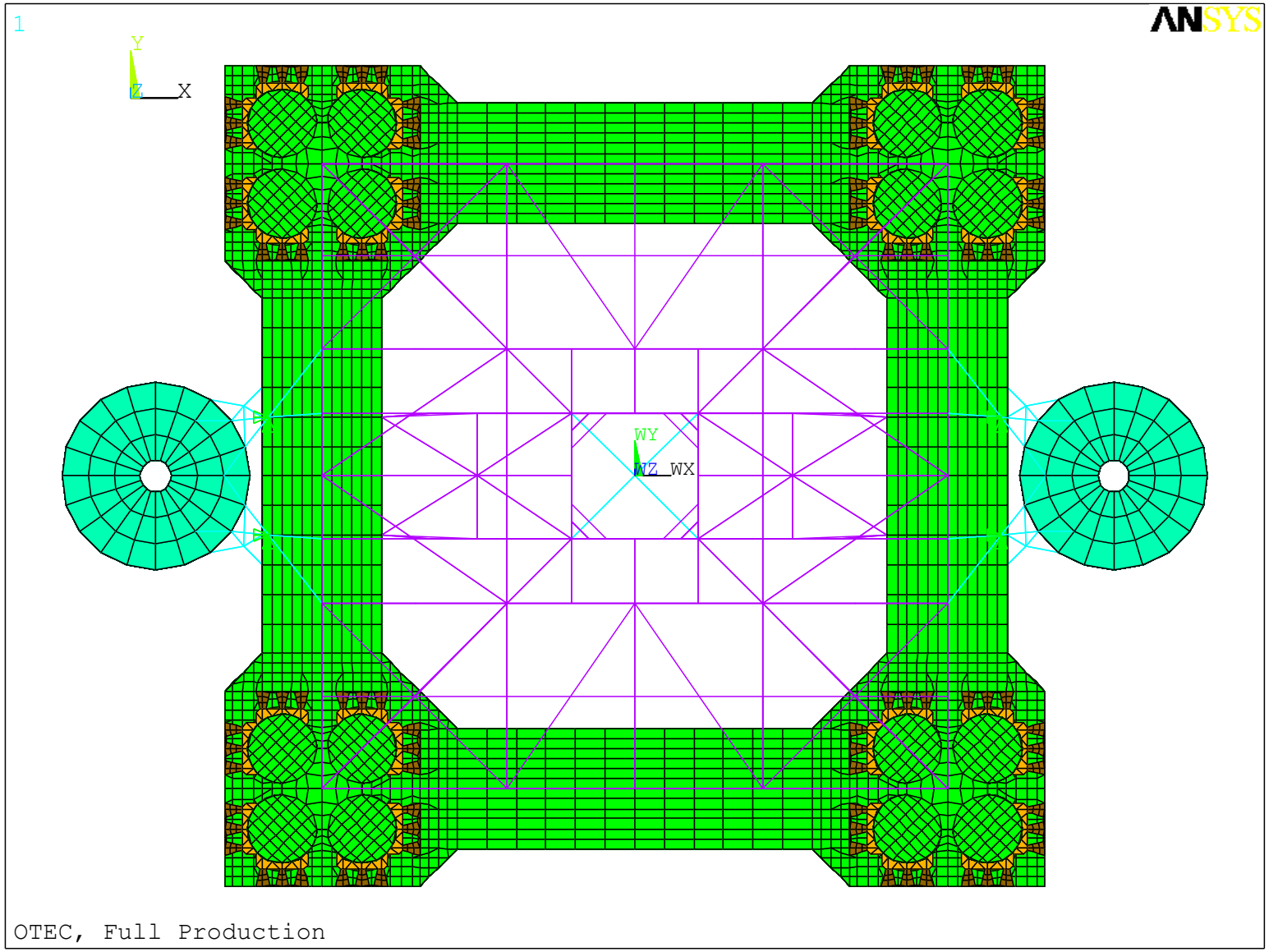
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JUL 3 2010
15:06:25
PLOT NO. 7
NODES
REAL NUM
U
CP

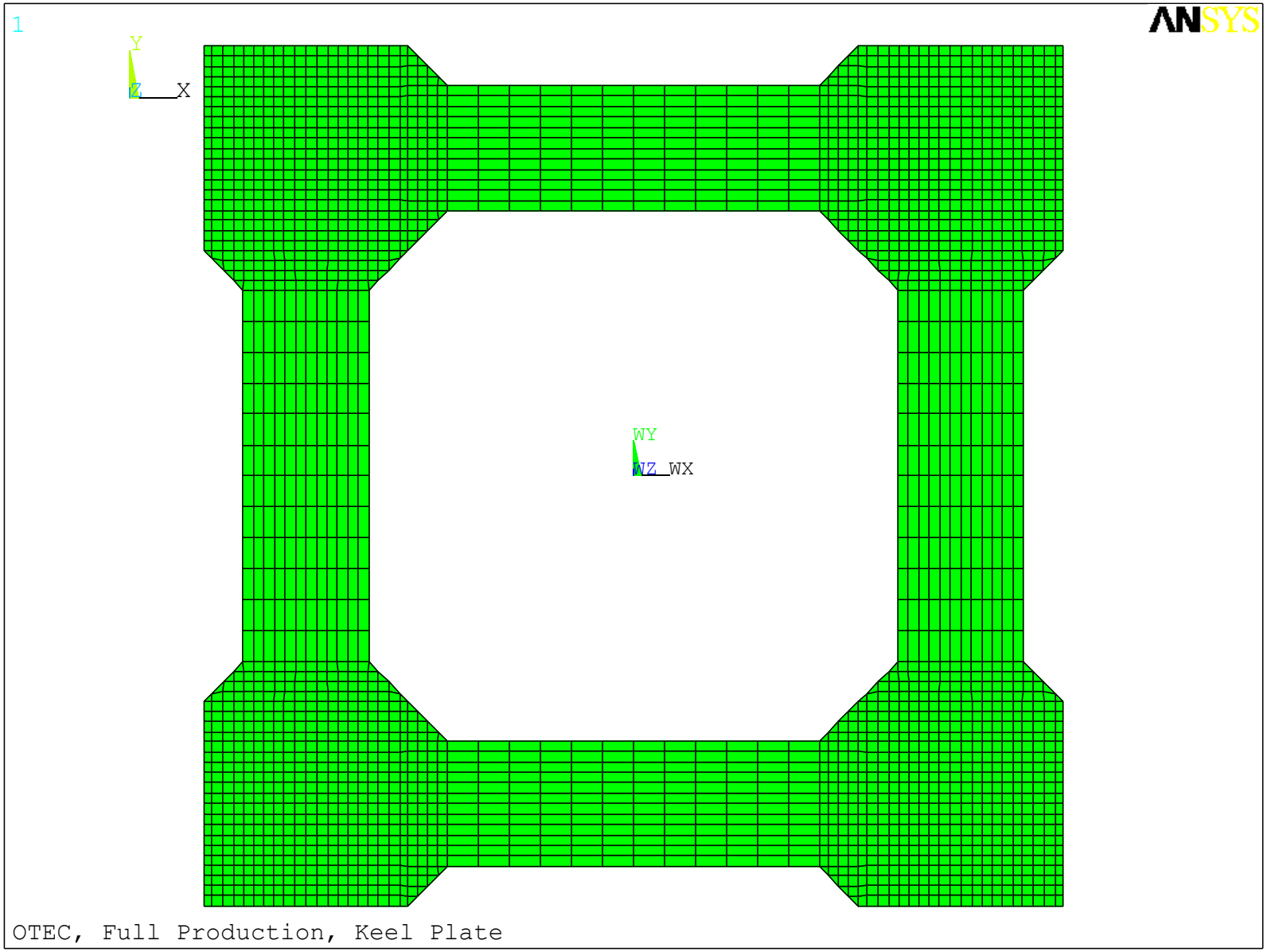


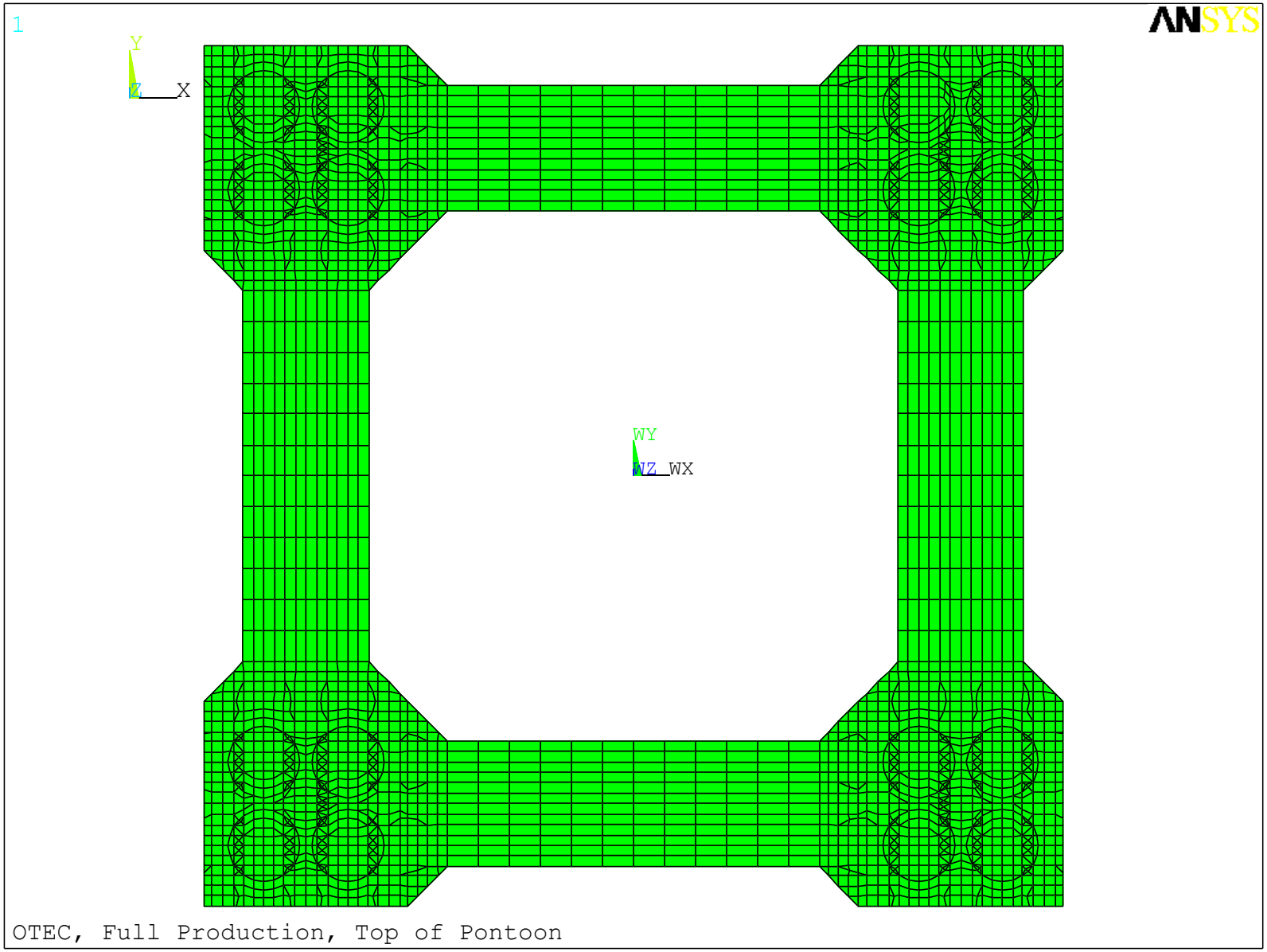
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JUL 3 2010
15:05:56
PLOT NO. 6
NODES
REAL NUM
U
CP

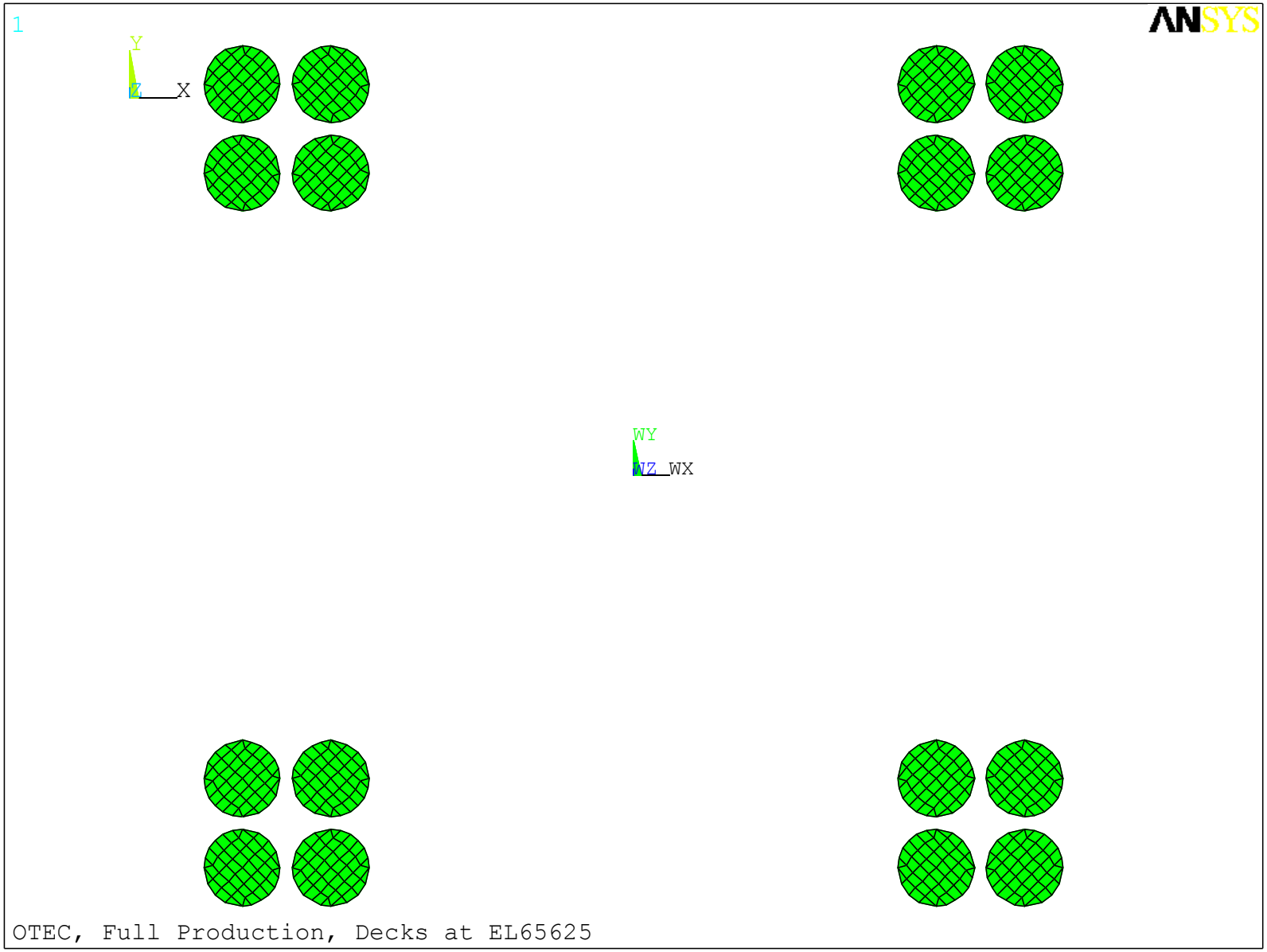

1
ANSYS
Y
Z
X
WZ
WY
WX
OTEC, Full Production

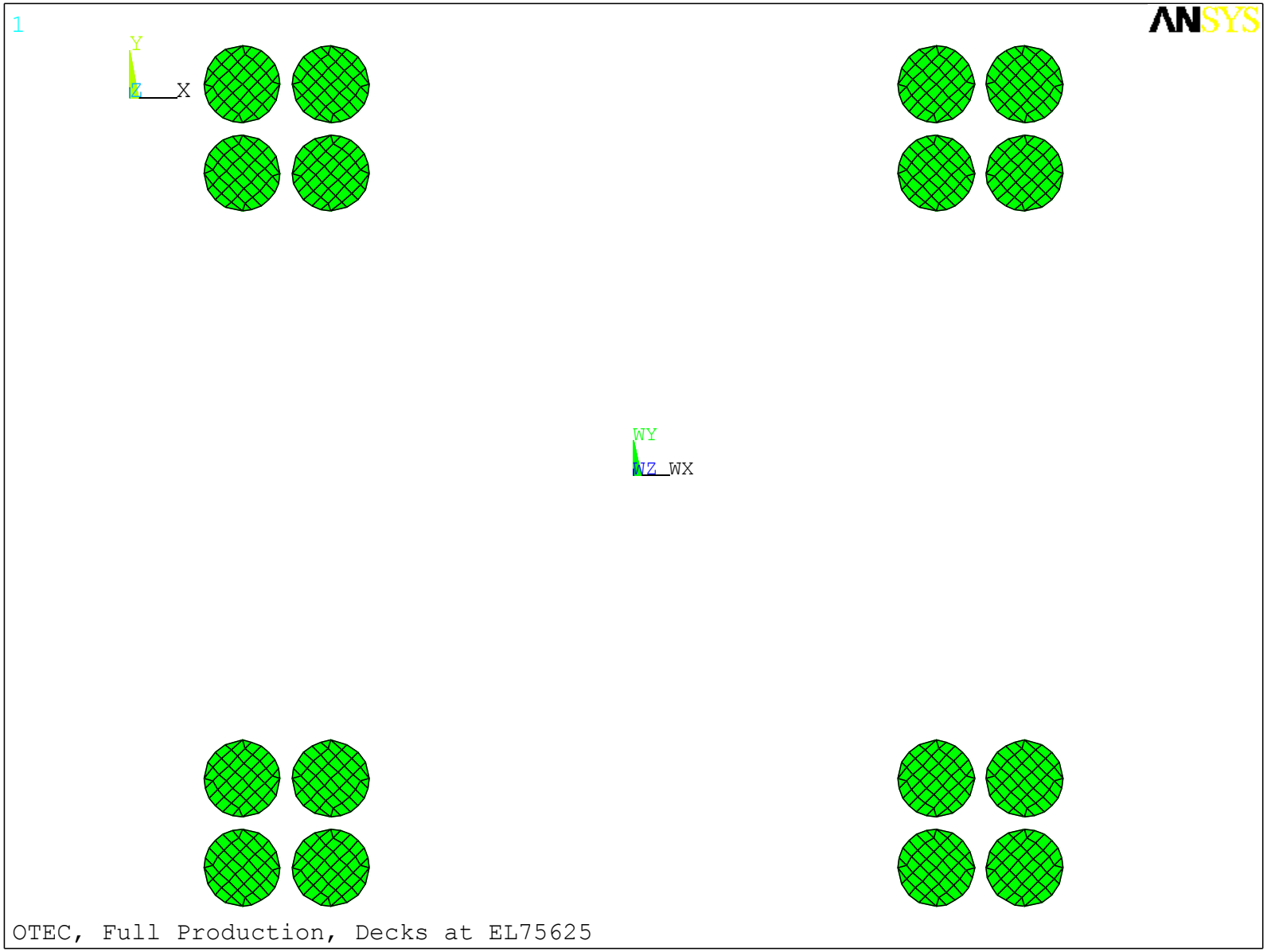

1
ANSYS
Z
X
WZ
WX
OTEC, Full Production

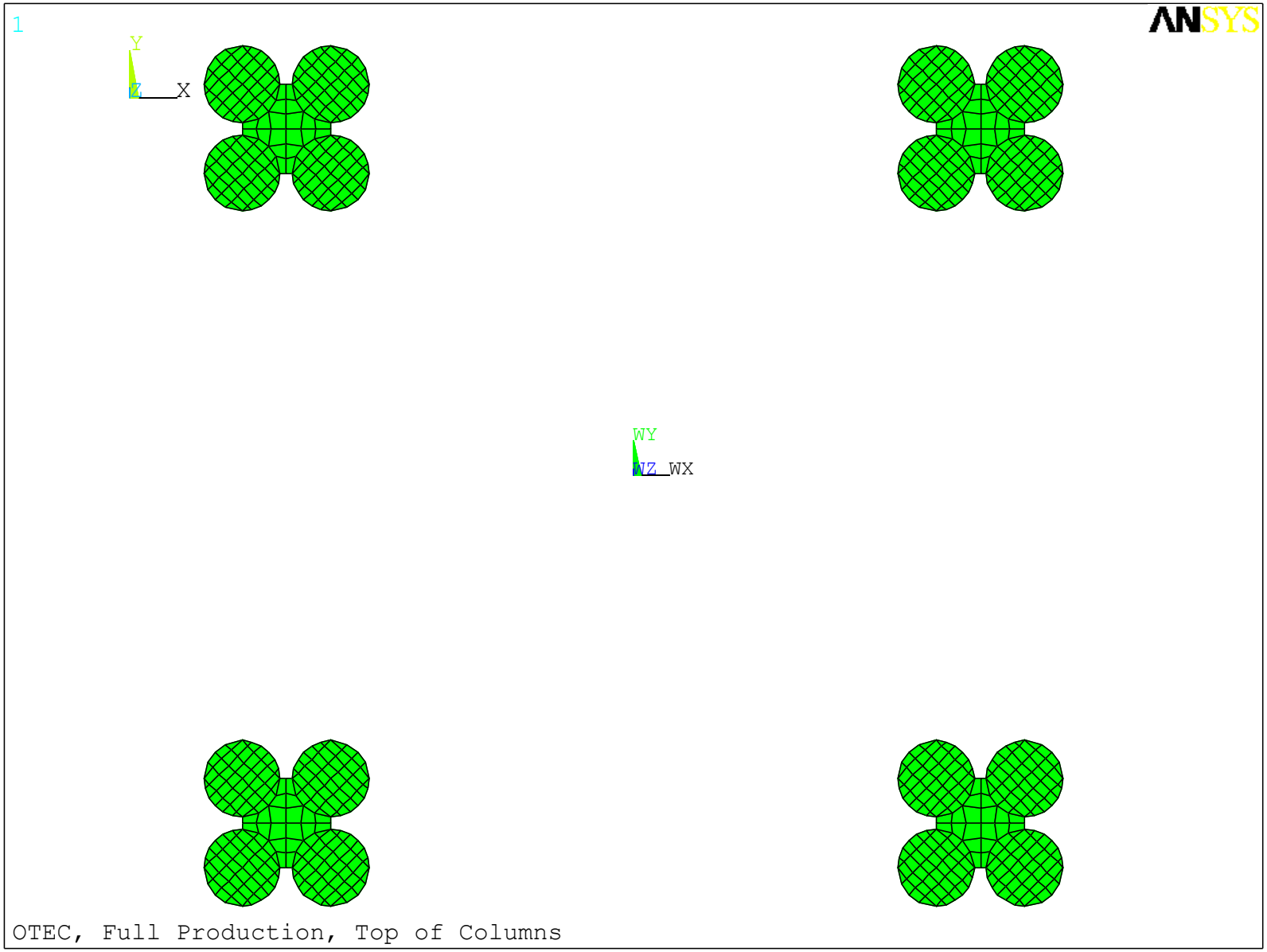

1
ANSYS
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Z
X
WY
WZ
WX
OTEC, Full Production

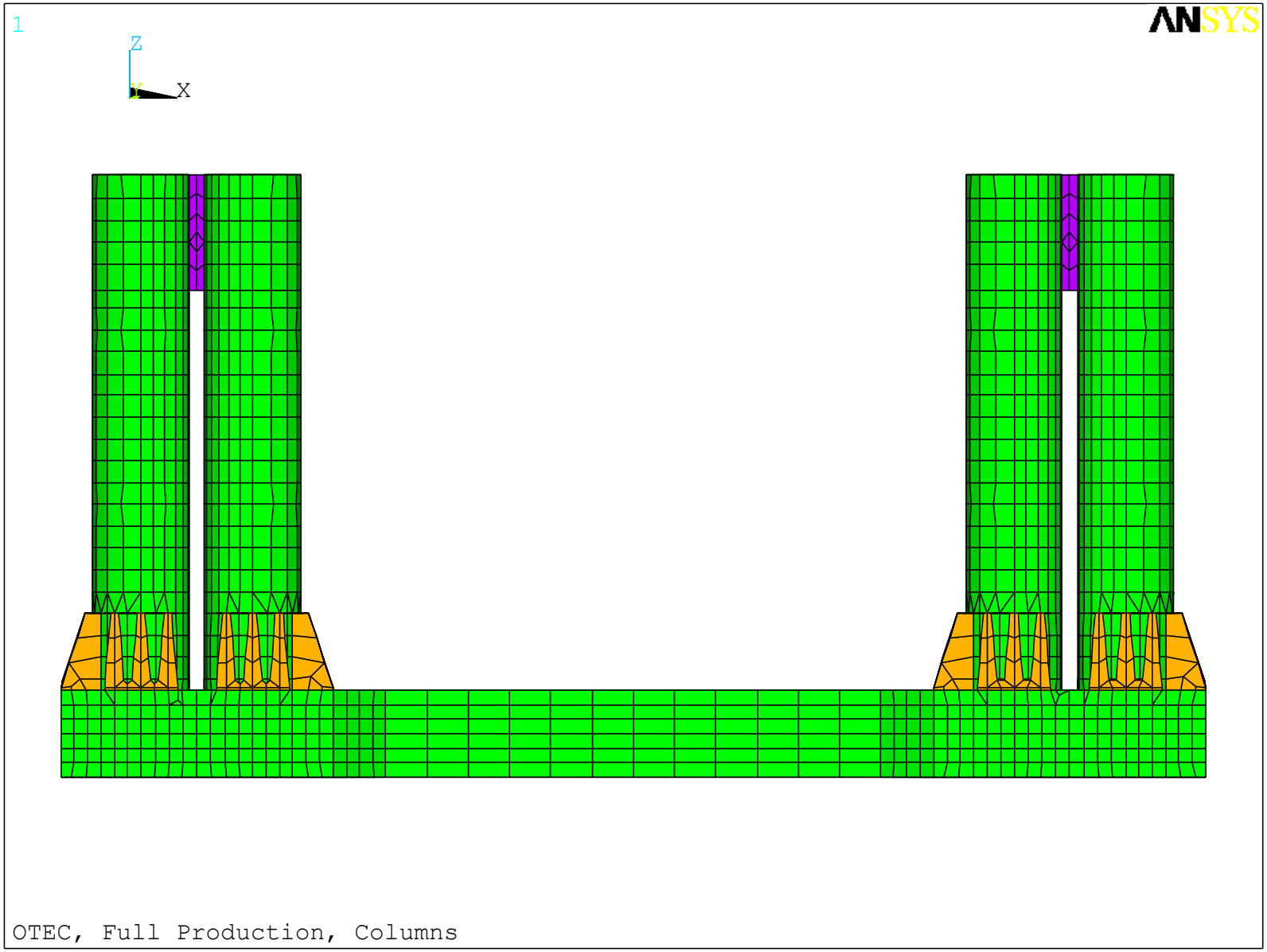

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Z
X
WY
WZ
WX
OTEC, Full Production, Keel Plate

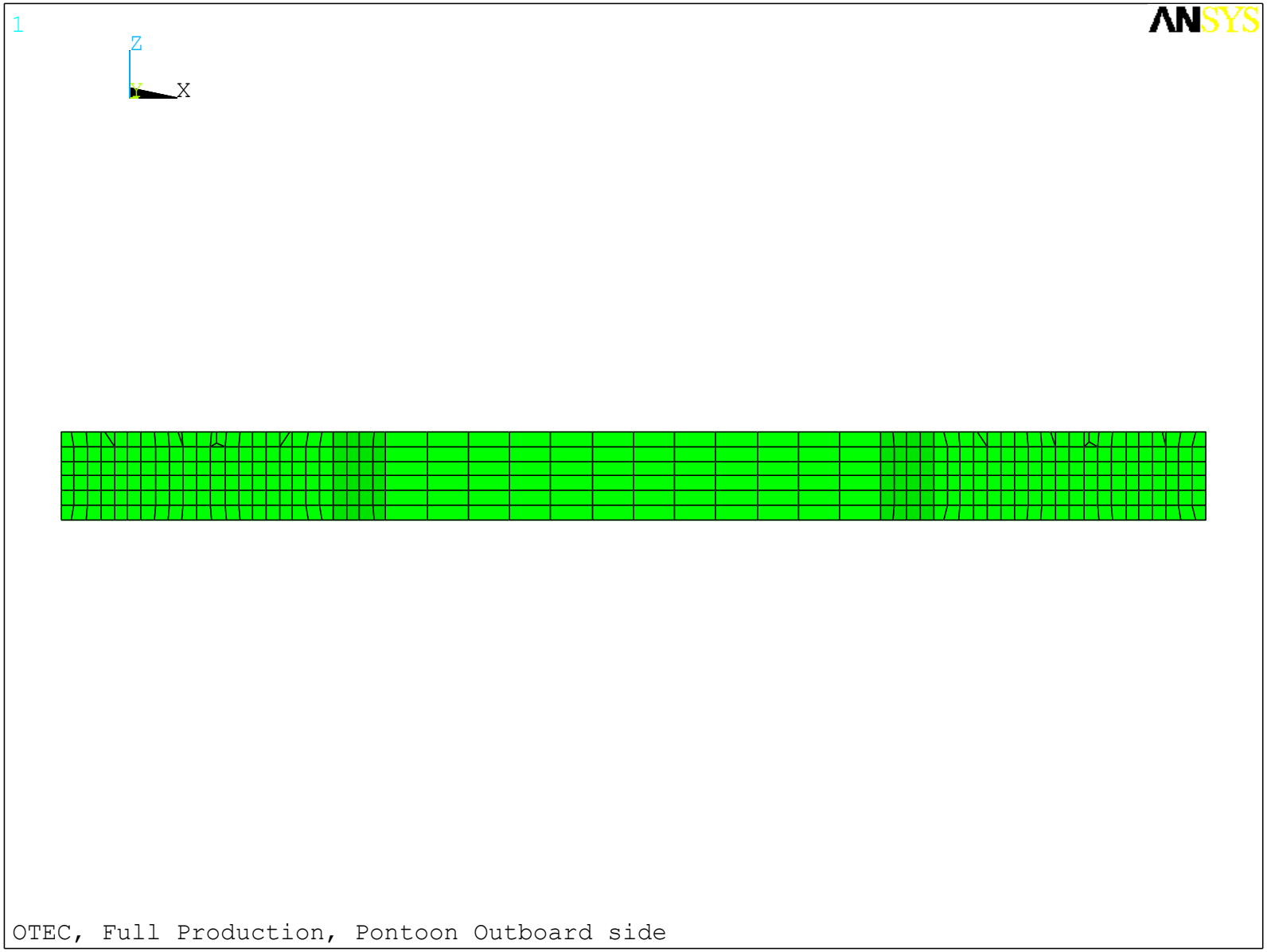

1
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Z
X
WY
WZ
WX
OTEC, Full Production, Top of Pontoon

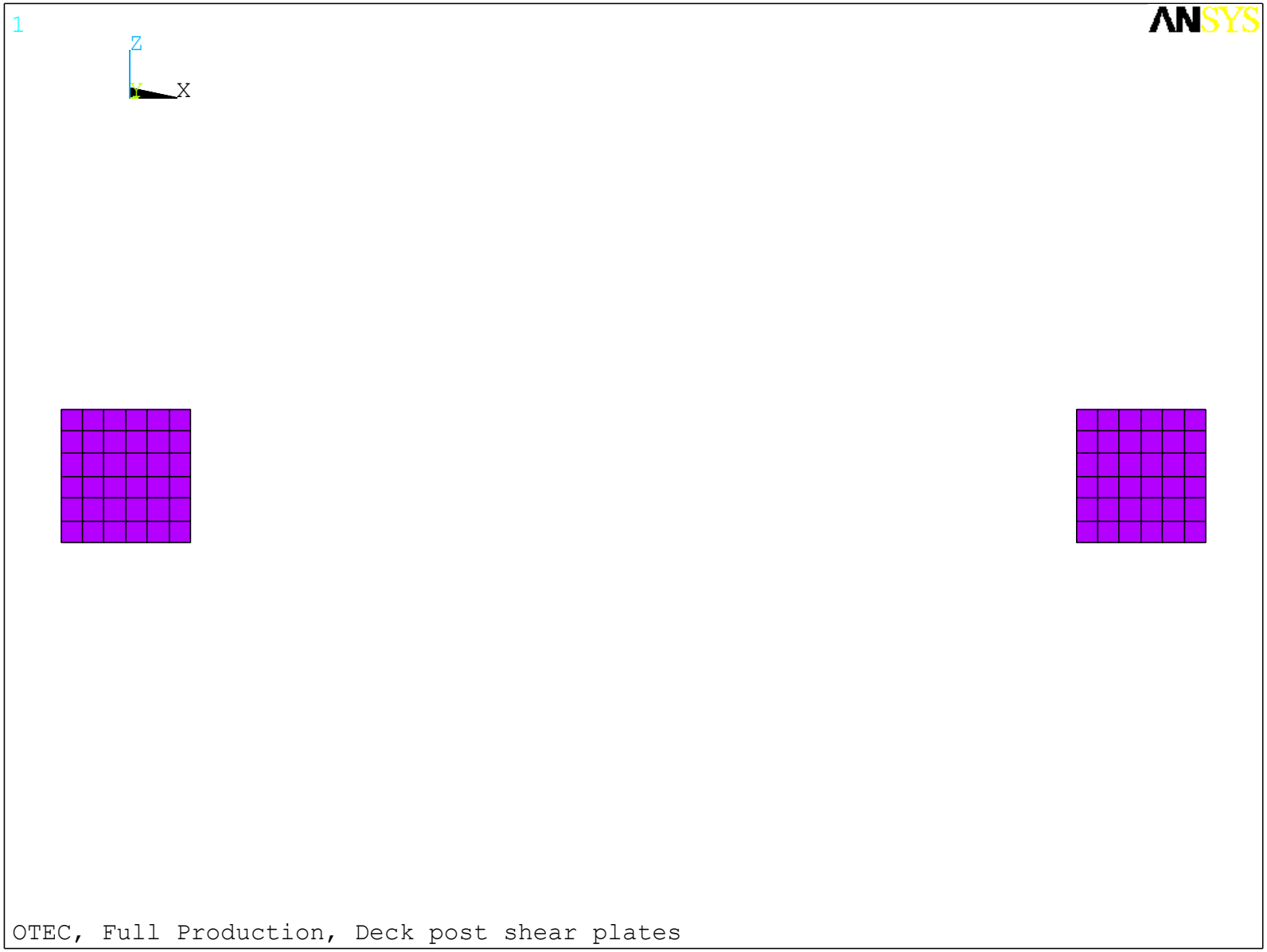

1
ANSYS
Y
Z
X
WY
WZ
WX
OTEC, Full Production, Decks at EL65625


1
ANSYS
Y
Z
X
WY
WZ
WX
OTEC, Full Production, Decks at EL75625

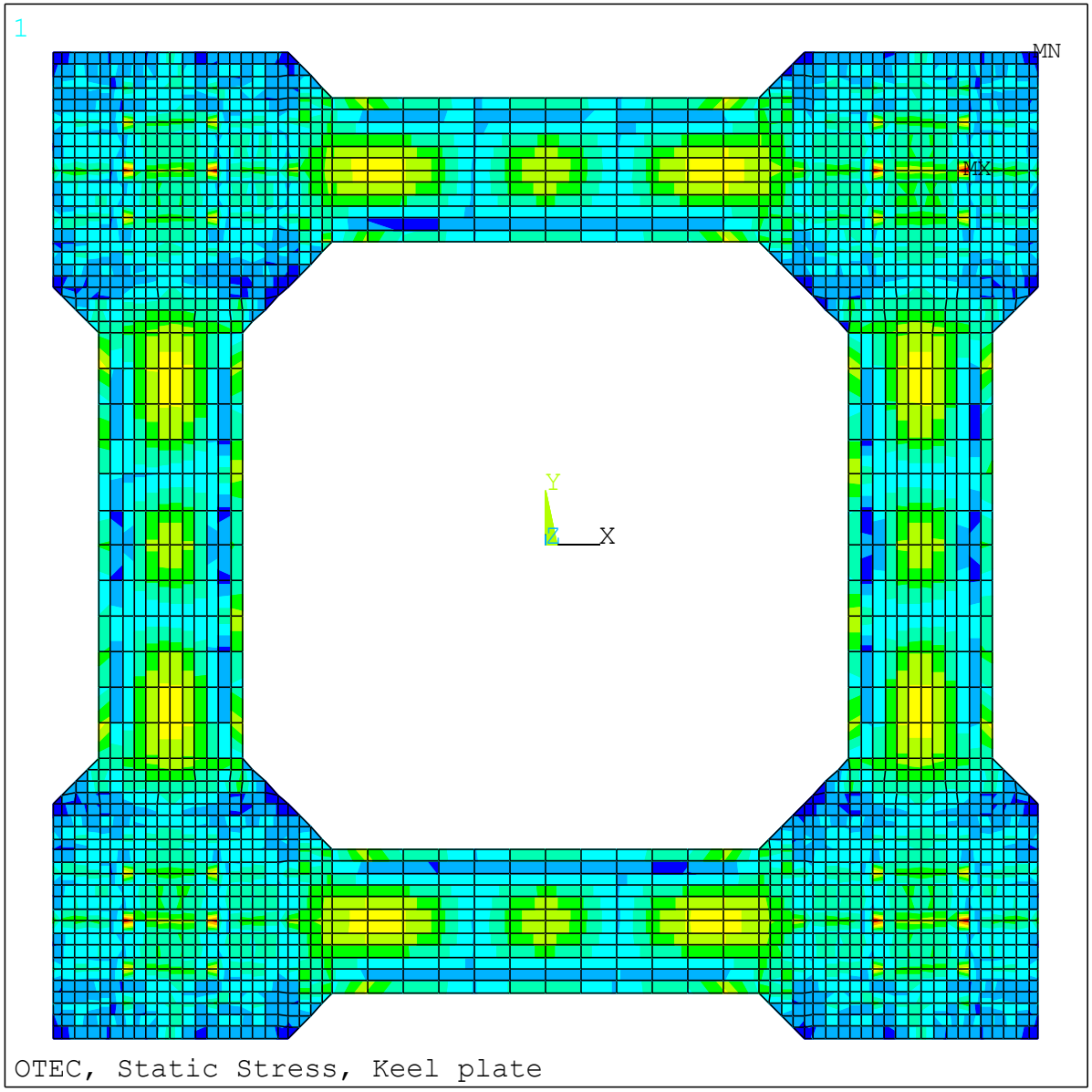

1
ANSYS
Y
Z
X
WY
WZ
WX
OTEC, Full Production, Top of Columns


1
ANSYS
Z
X
OTEC, Full Production, Columns


1
Z
X
ANSYS
OTEC, Full Production, Pontoon Outboard side

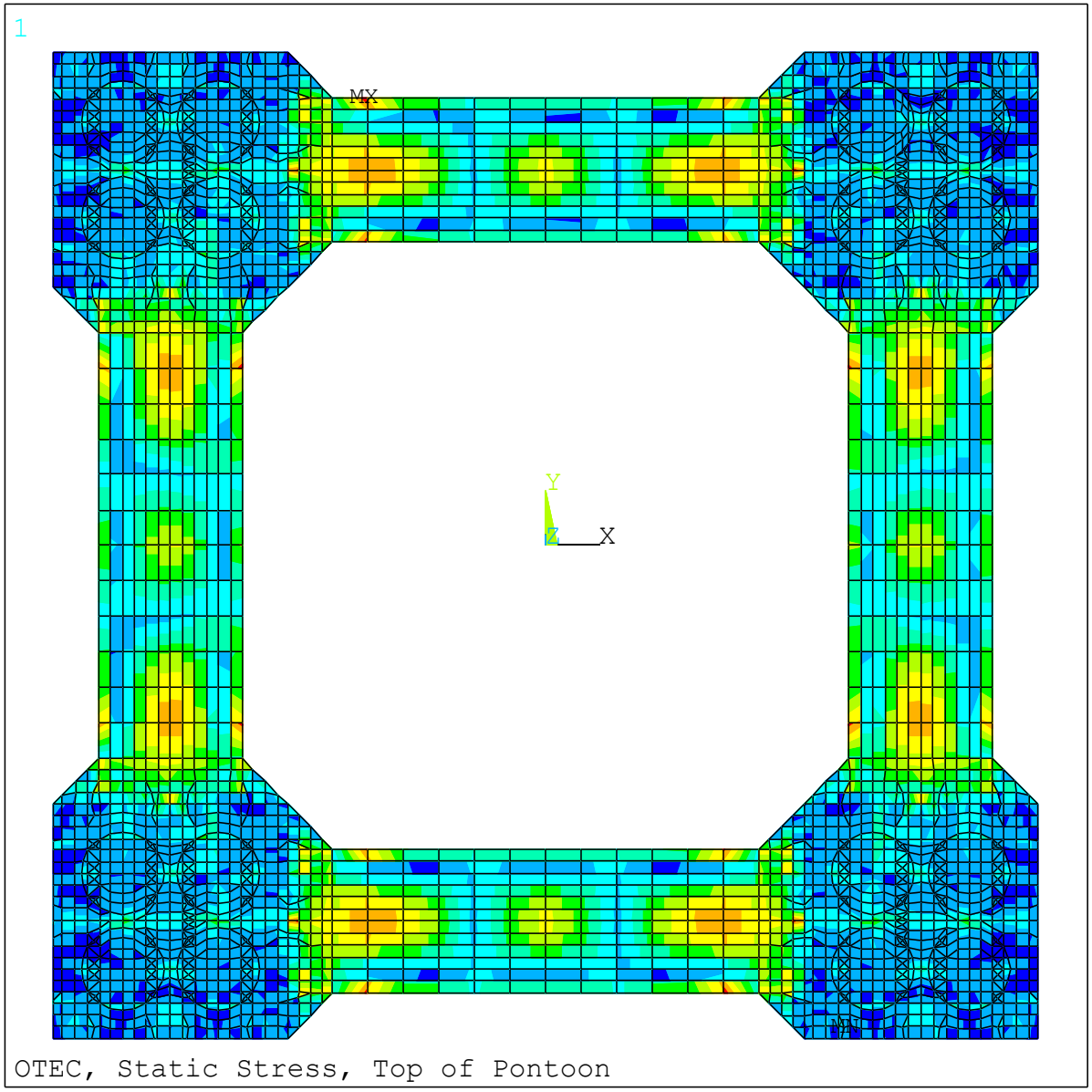

1
ANSYS
Z
X
OTEC, Full Production, Deck post shear plates

Control Group ID	Descriptions	Element numbers							
C001	Pontoon keel at Remora Connections	16622	16627	685	683	27039	27034	37435	37430
C002	Pontoon keel at mid span	10971	31741	21383	525	11003	681	21415	37423
C003	Pontoon top at column bkt connections	1507	1441	26931	26749	37145	37327	16519	16337
C004	Pontoon top at mid span	543	26299	26485	36885	36699	15887	16073	609
C005	Node keel at pontoon connections	37690	16882	16643	691	767	27294	27055	37451
C006	Node to pontoon inboard side connections	18469	19424	938	879	28876	29827	40163	39236
C007	Node to pontoon outboard side connections	19402	40141	931	19410	29805	928	40149	29813
C008	Column to node bracket connections	34283	34272	23879	23918	5370	4920	13506	13467
C009	Column to Deck connections (at bottom)	21674	21656	32074	32056	11262	11244	2929	2947
C010	Column to Deck connections (at top)	3091	2981	22547	21882	12140	12082	32947	32282



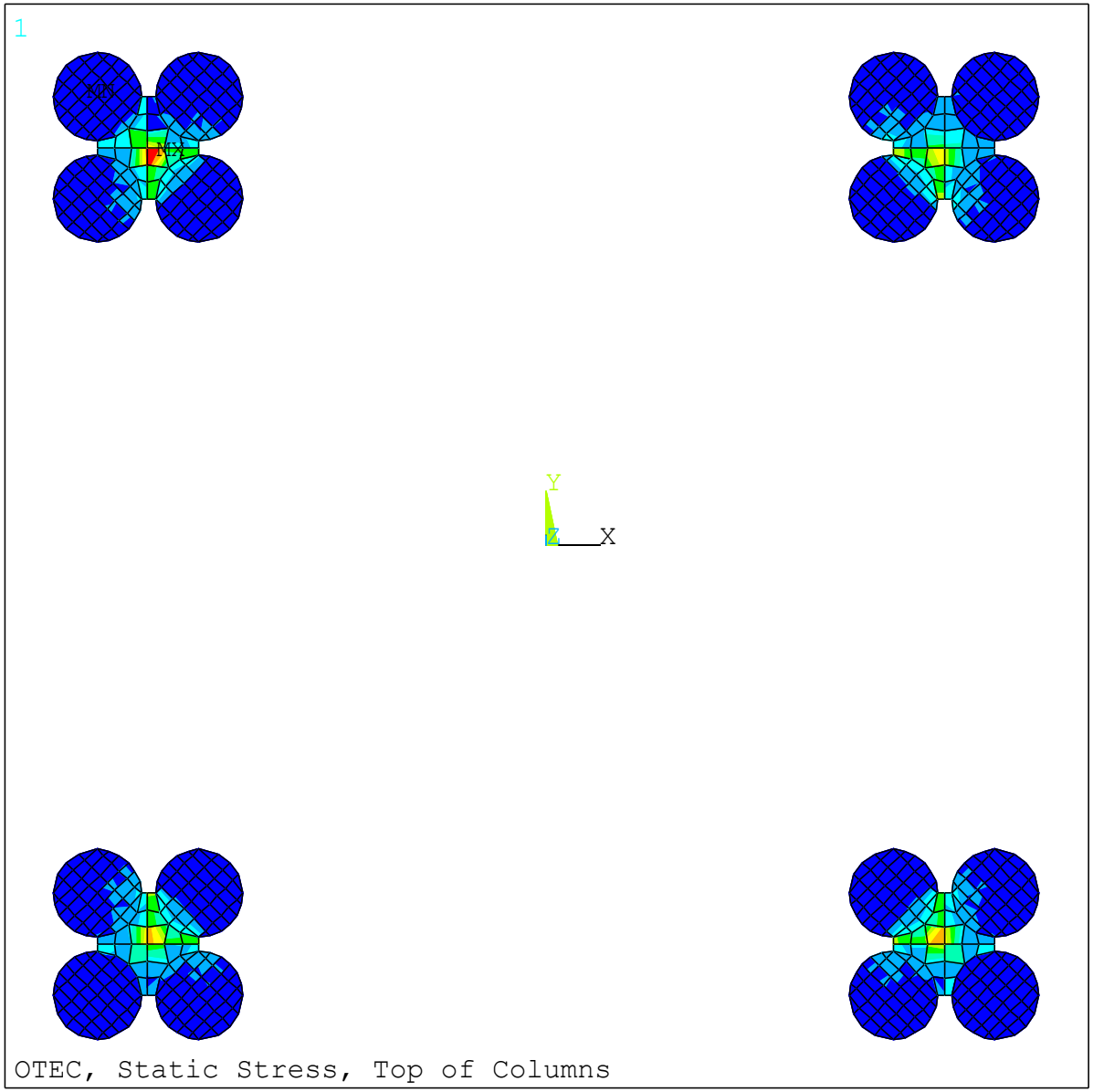
ANSYS 11.0
AUG 16 2010
17:35:39
PLOT NO. 1
ELEMENT SOLUTION
STEP=1
SUB =1
TIME=1
SEQV (NOAVG)
MIDDLE
DMX =379.928
SMN =3.954
SMX =121.003

3.954
16.959
29.964
42.97
55.975
68.981
81.986
94.992
107.997
121.003



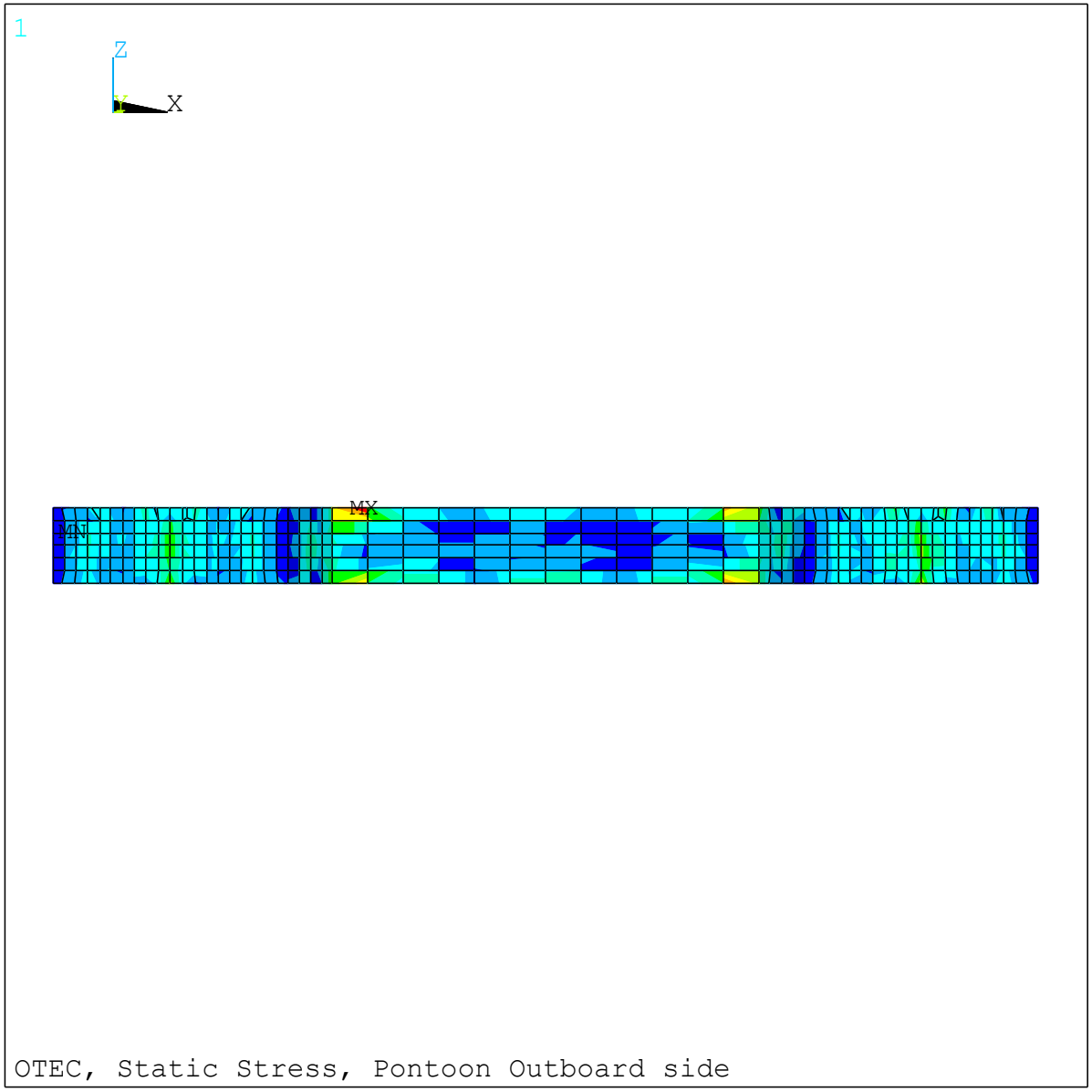
ANSYS 11.0
AUG 16 2010
17:36:27
PLOT NO. 2
ELEMENT SOLUTION
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SUB =1
TIME=1
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SMN =1.035
SMX =109.994

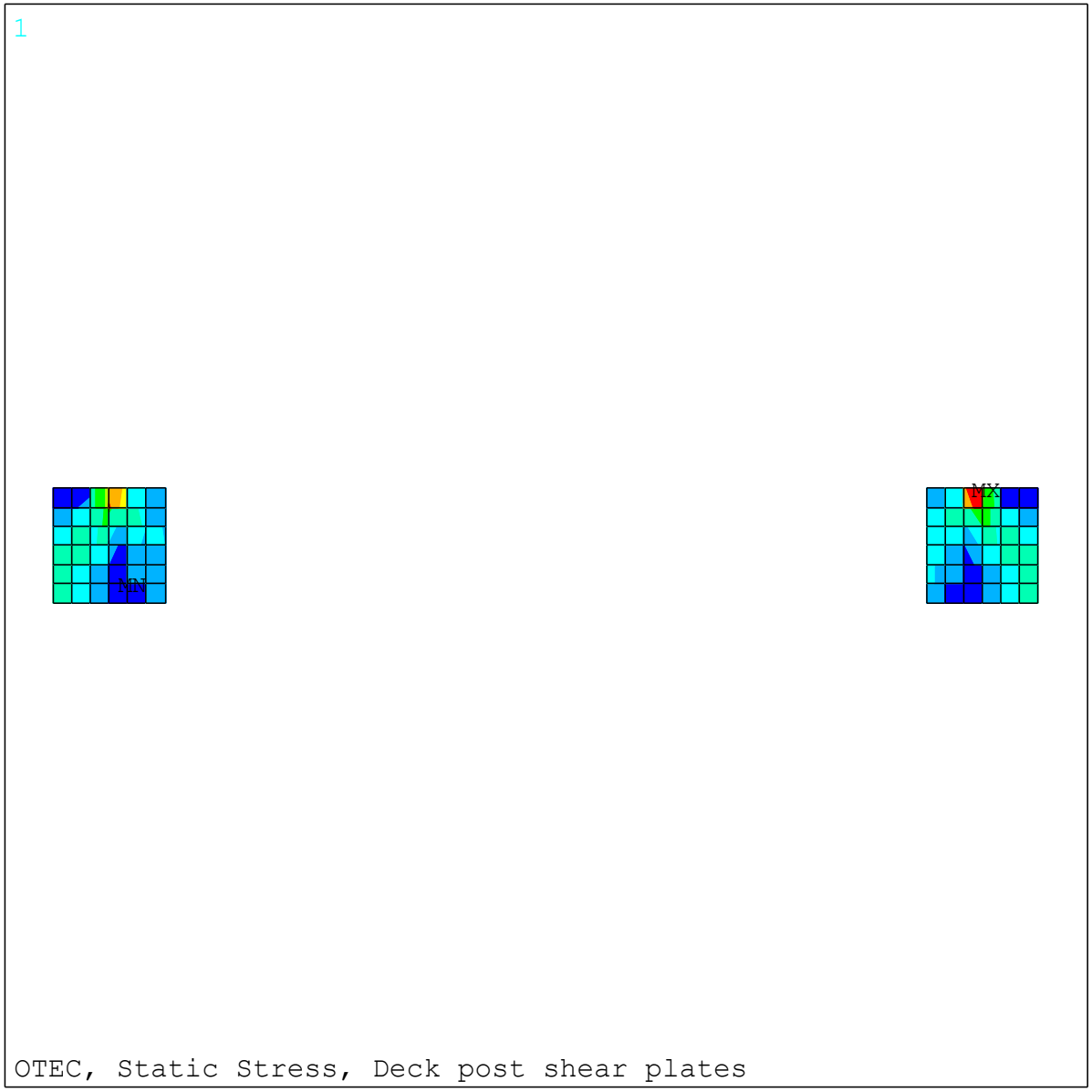
1.035
13.141
25.248
37.355
49.461
61.568
73.674
85.781
97.888
109.994



ANSYS 11.0
AUG 16 2010
17:37:07
PLOT NO. 3
ELEMENT SOLUTION
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MIDDLE
DMX =462.992
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SMX =41.237

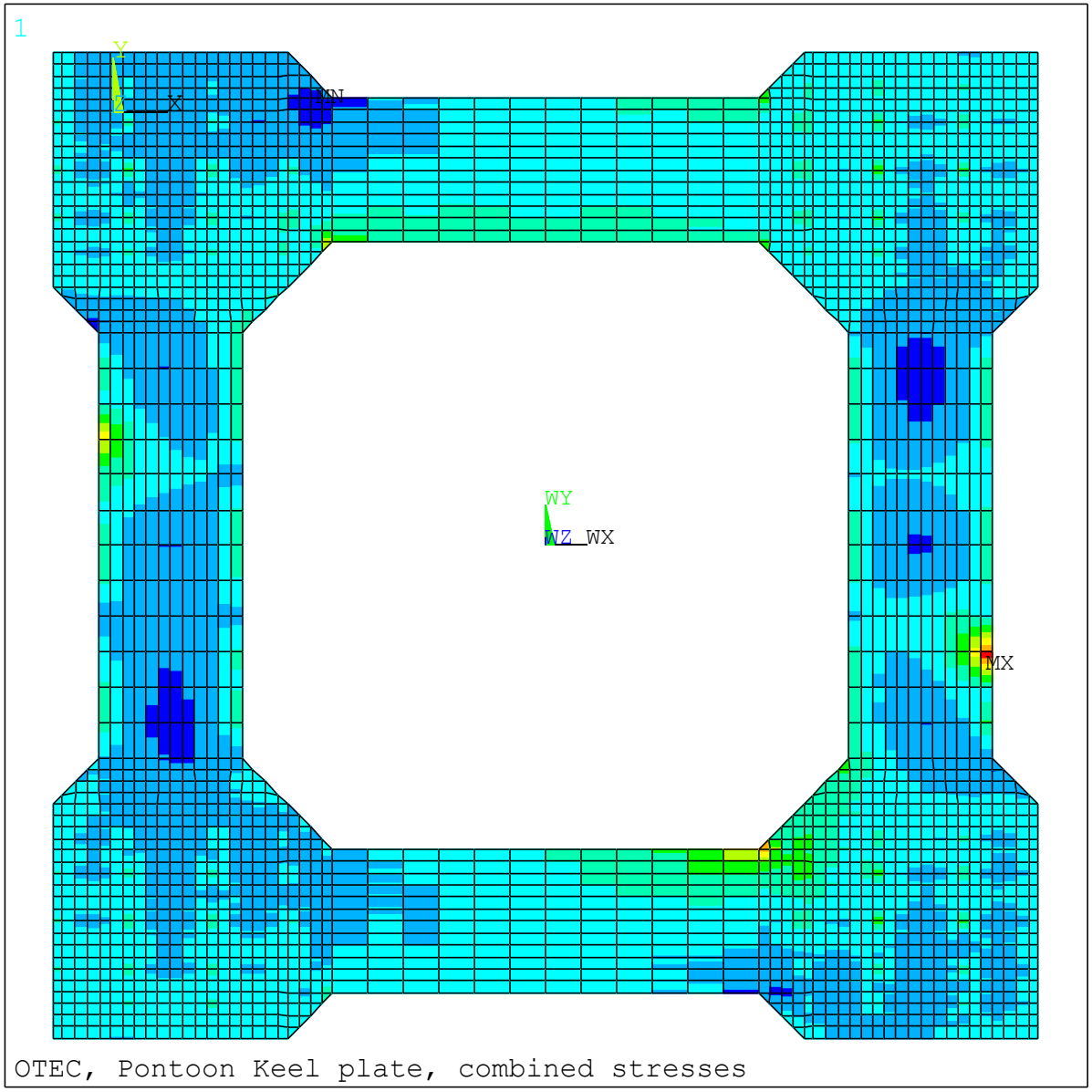
.071721
4.646
9.22
13.794
18.367
22.941
27.515
32.089
36.663
41.237

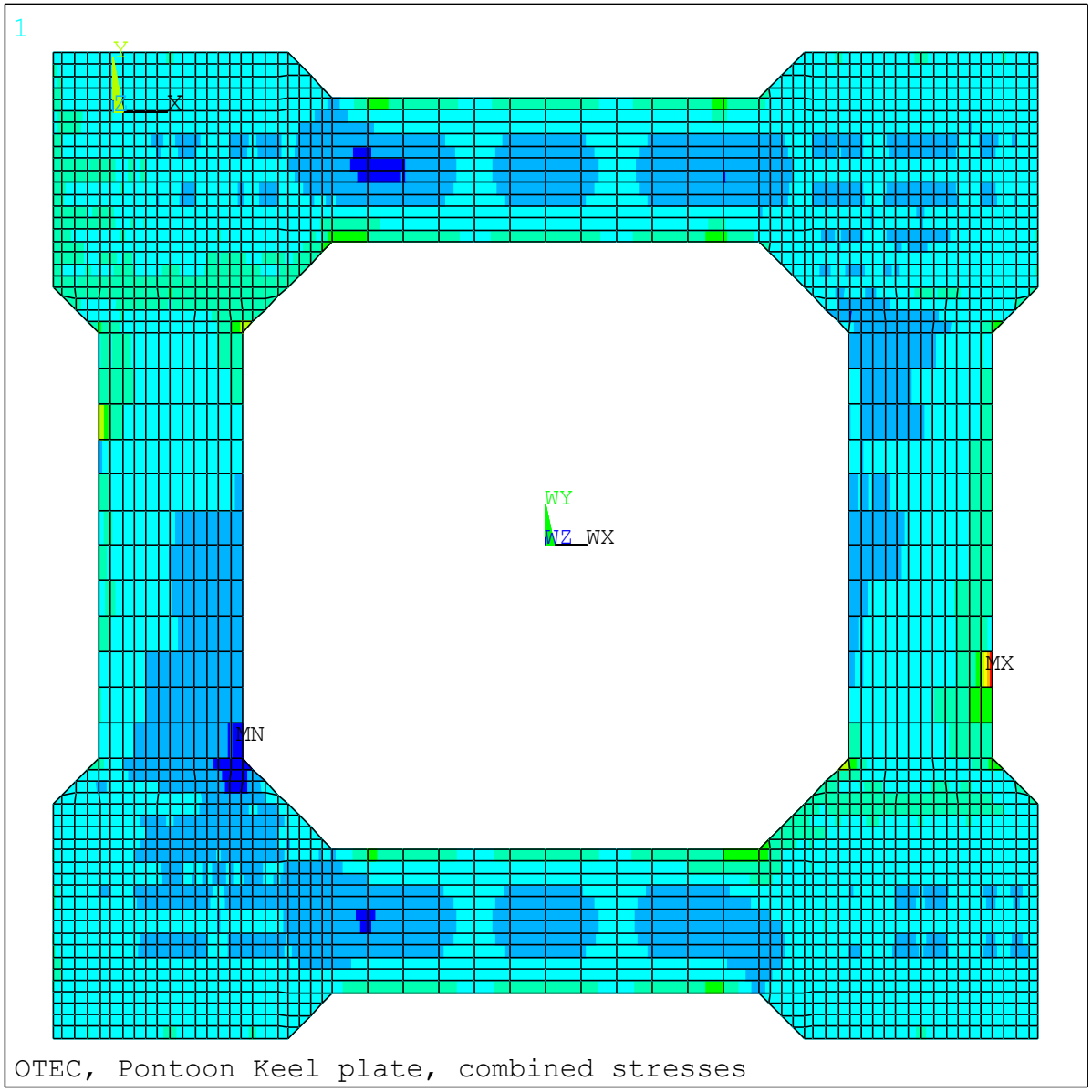

1
Z
X
MX
MN
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ELEMENT SOLUTION
STEP=1
SUB =1
TIME=1
SEQV (NOAVG)
MIDDLE
DMX =329.787
SMN =1.683
SMX =93.916
1.683
11.931
22.179
32.427
42.675
52.923
63.171
73.419
83.667
93.916
OTEC, Static Stress, Pontoon Outboard side



ANSYS 11.0
AUG 16 2010
17:38:47
PLOT NO. 4
ELEMENT SOLUTION
STEP=1
SUB =1
TIME=1
SEQV (NOAVG)
MIDDLE
DMX =438.484
SMN =12.497
SMX =68.222

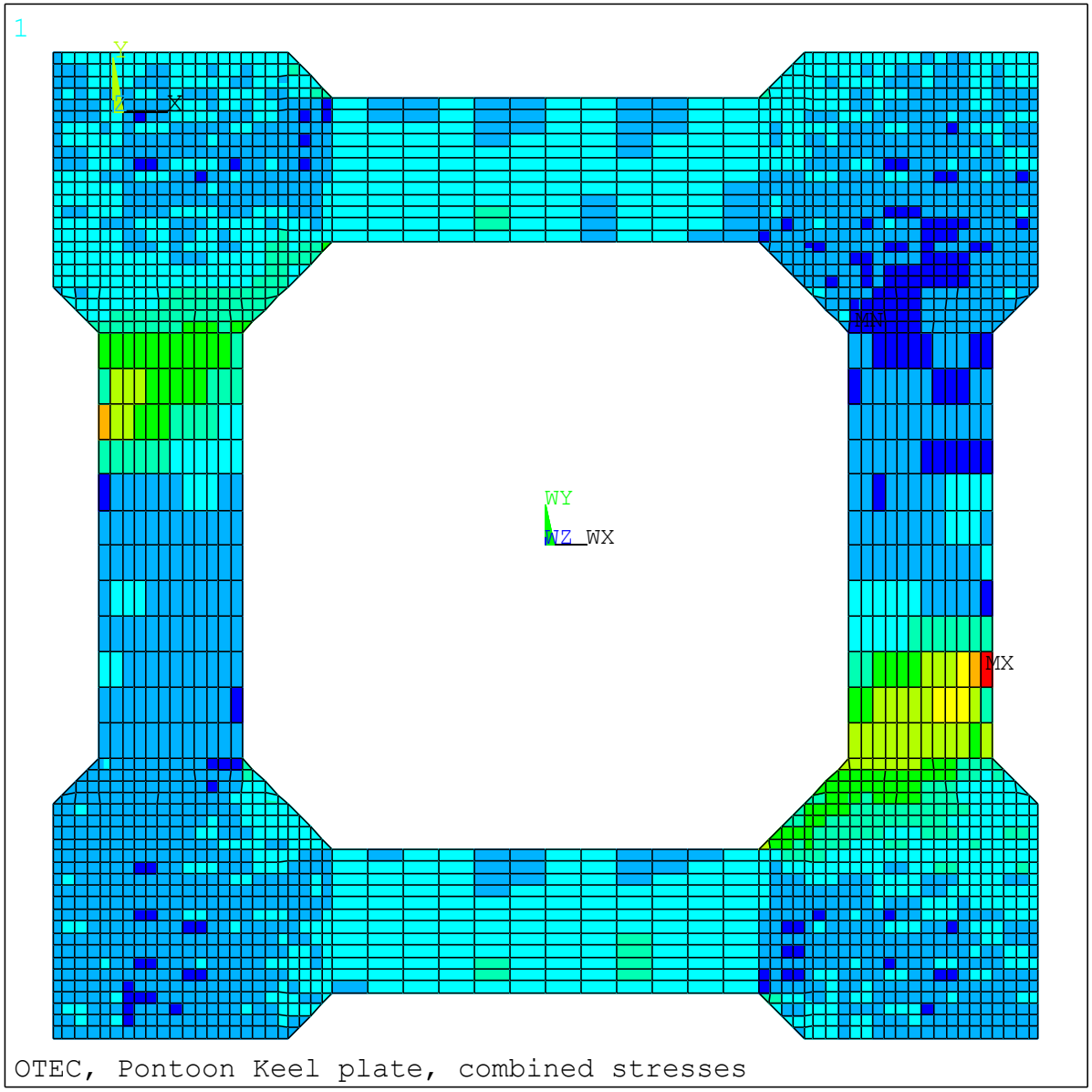
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24.88
31.072
37.263
43.455
49.647
55.838
62.03
68.222

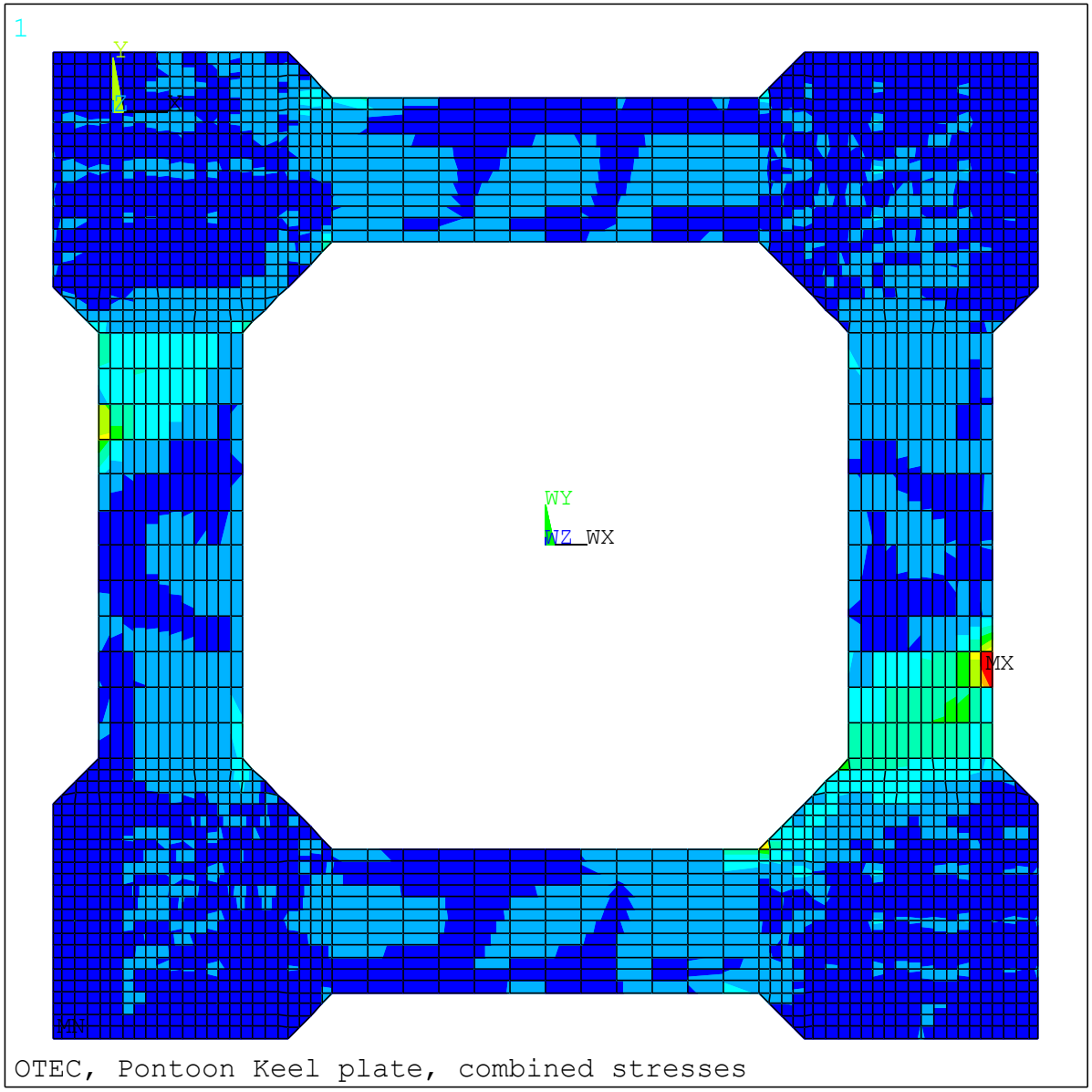

1
Y
X
MN
WY
WZ
WX
MX
ANSYS 11.0
AUG 16 2010
17:28:47
PLOT NO. 1
ELEMENT SOLUTION
STEP=9999
SX (NOAVG)
MIDDLE
RSYS=0
DMX =1539
SMN =-153.438
SMX =416.31
-153.438
-90.133
-26.827
36.478
99.783
163.089
226.394
289.699
353.004
416.31
OTEC, Pontoon Keel plate, combined stresses



ANSYS 11.0
AUG 16 2010
17:28:47
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SMX =332.445

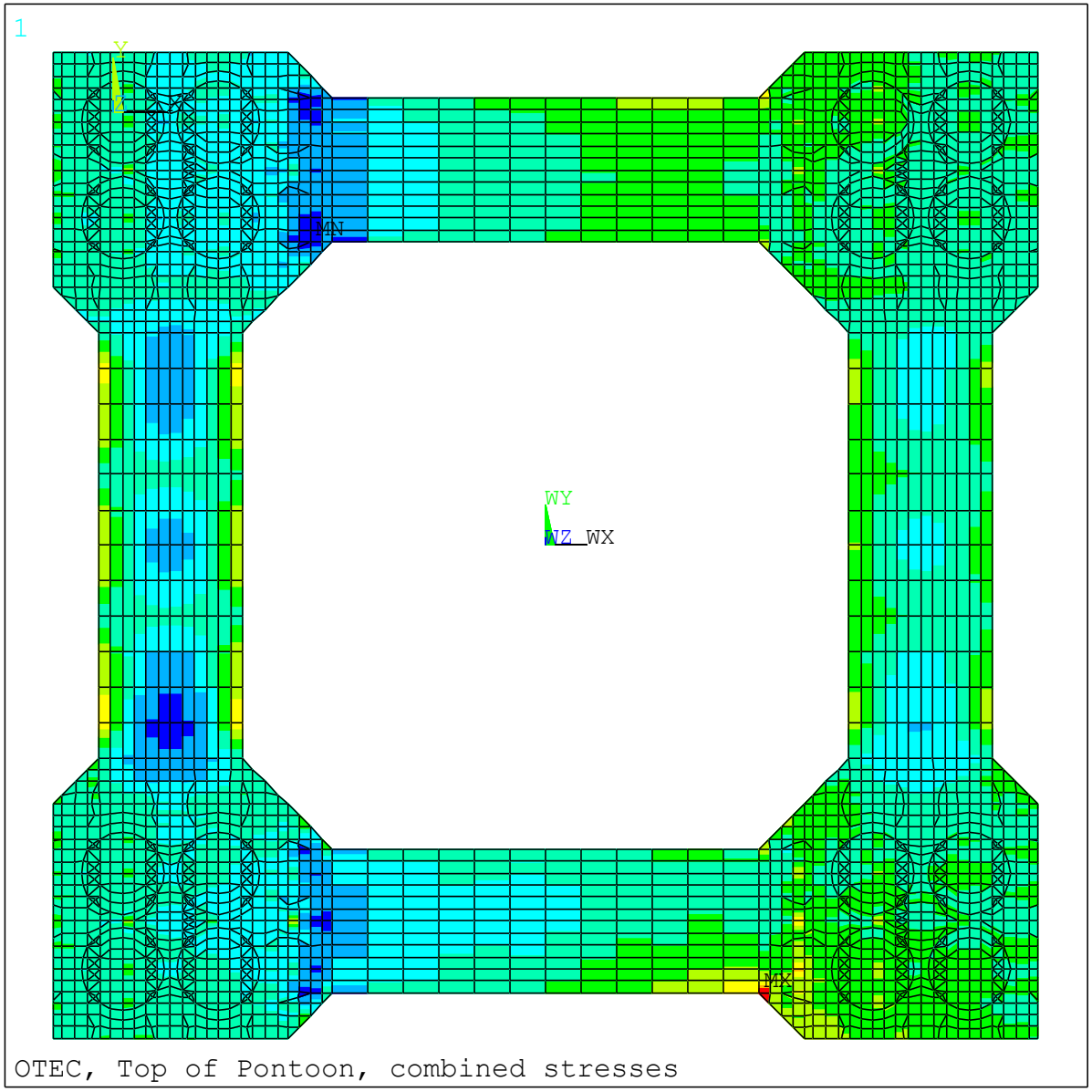
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-98.61
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332.445

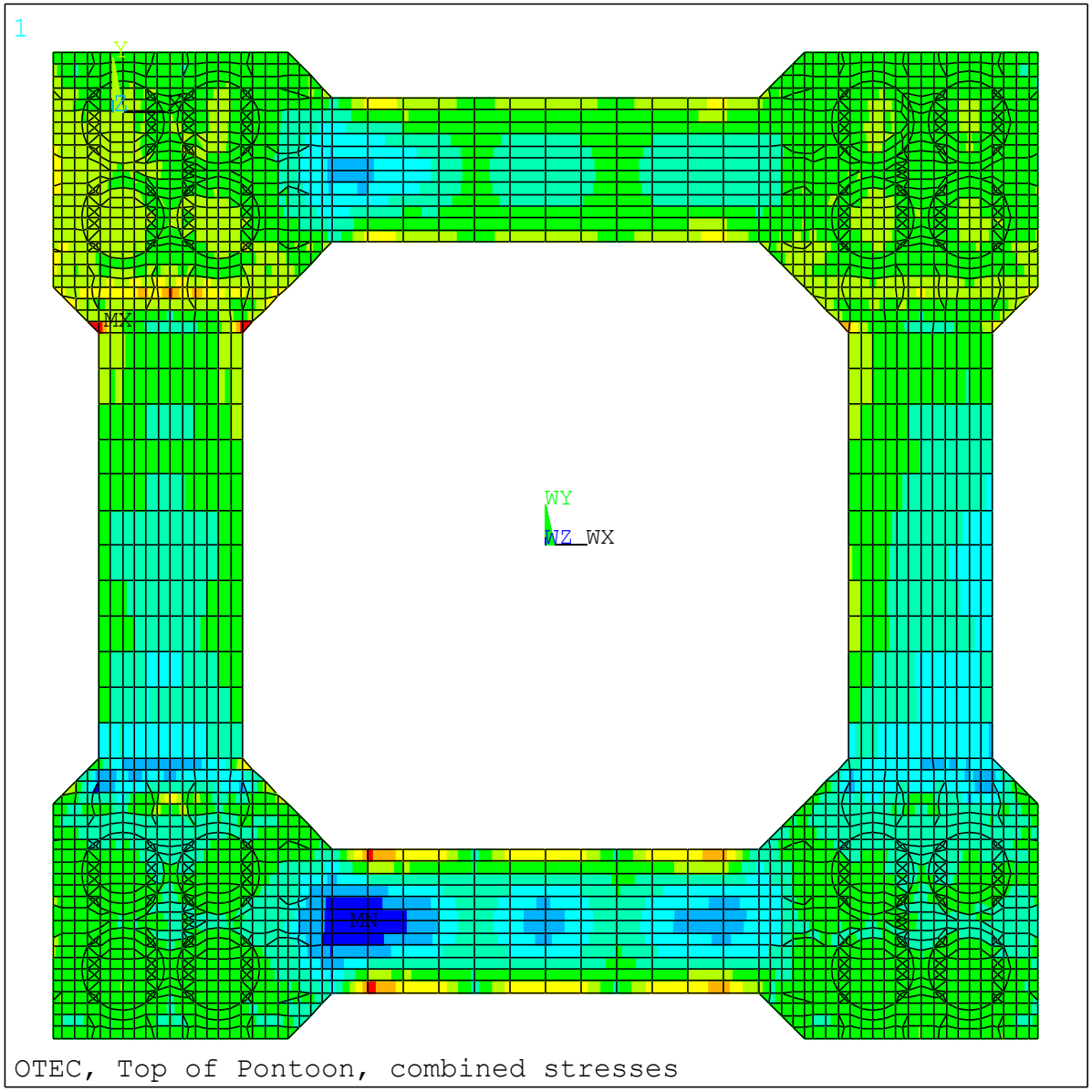

1
Y
X
MN
WY
WZ
WX
MX
ANSYS 11.0
AUG 16 2010
17:28:48
PLOT NO. 3
ELEMENT SOLUTION
STEP=9999
SXY (NOAVG)
MIDDLE
RSYS=0
DMX =1539
SMN =-61.15
SMX =218.52
-61.15
-30.076
.998579
32.073
63.148
94.222
125.297
156.371
187.446
218.52
OTEC, Pontoon Keel plate, combined stresses



ANSYS 11.0
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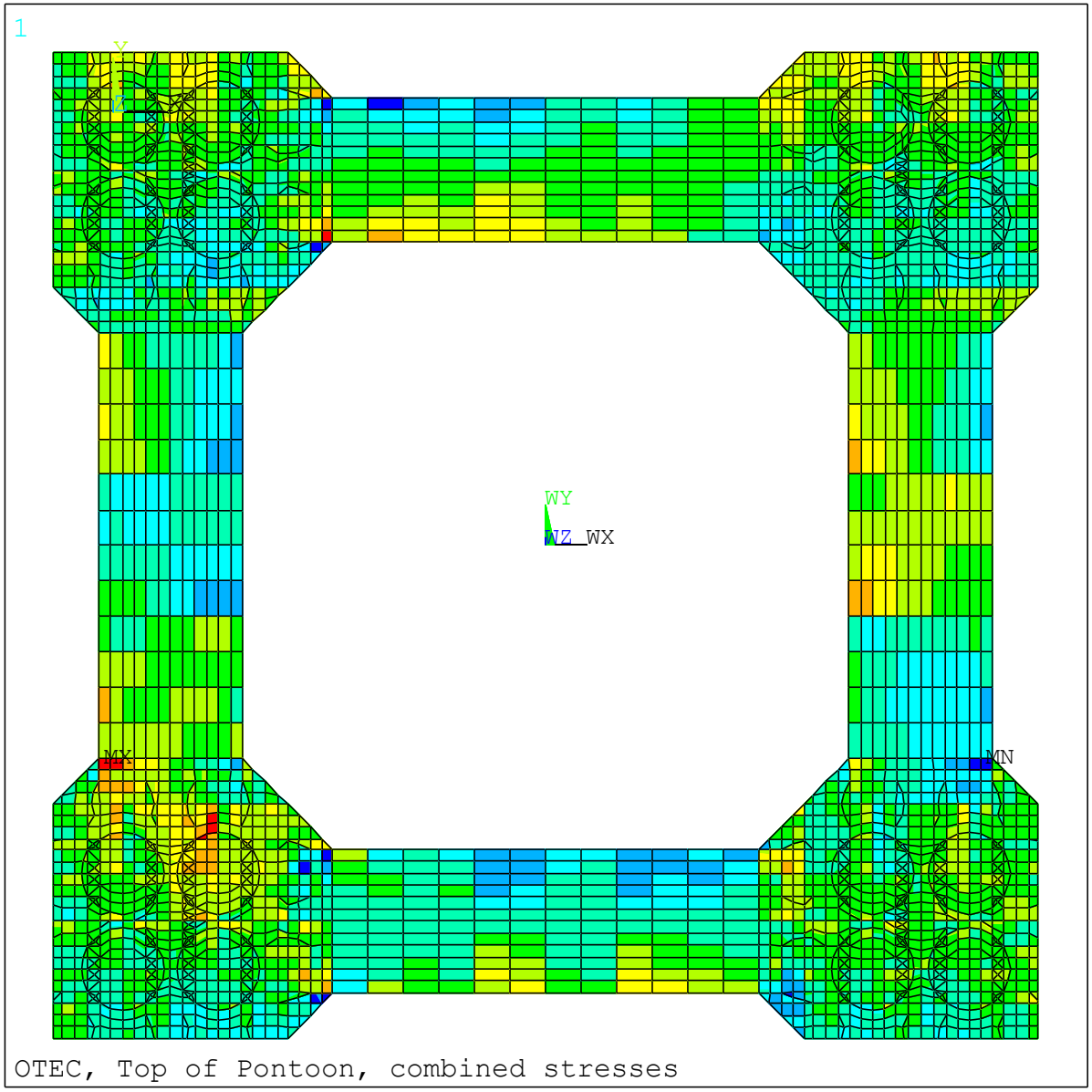

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WZ
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OTEC, Top of Pontoon, combined stresses
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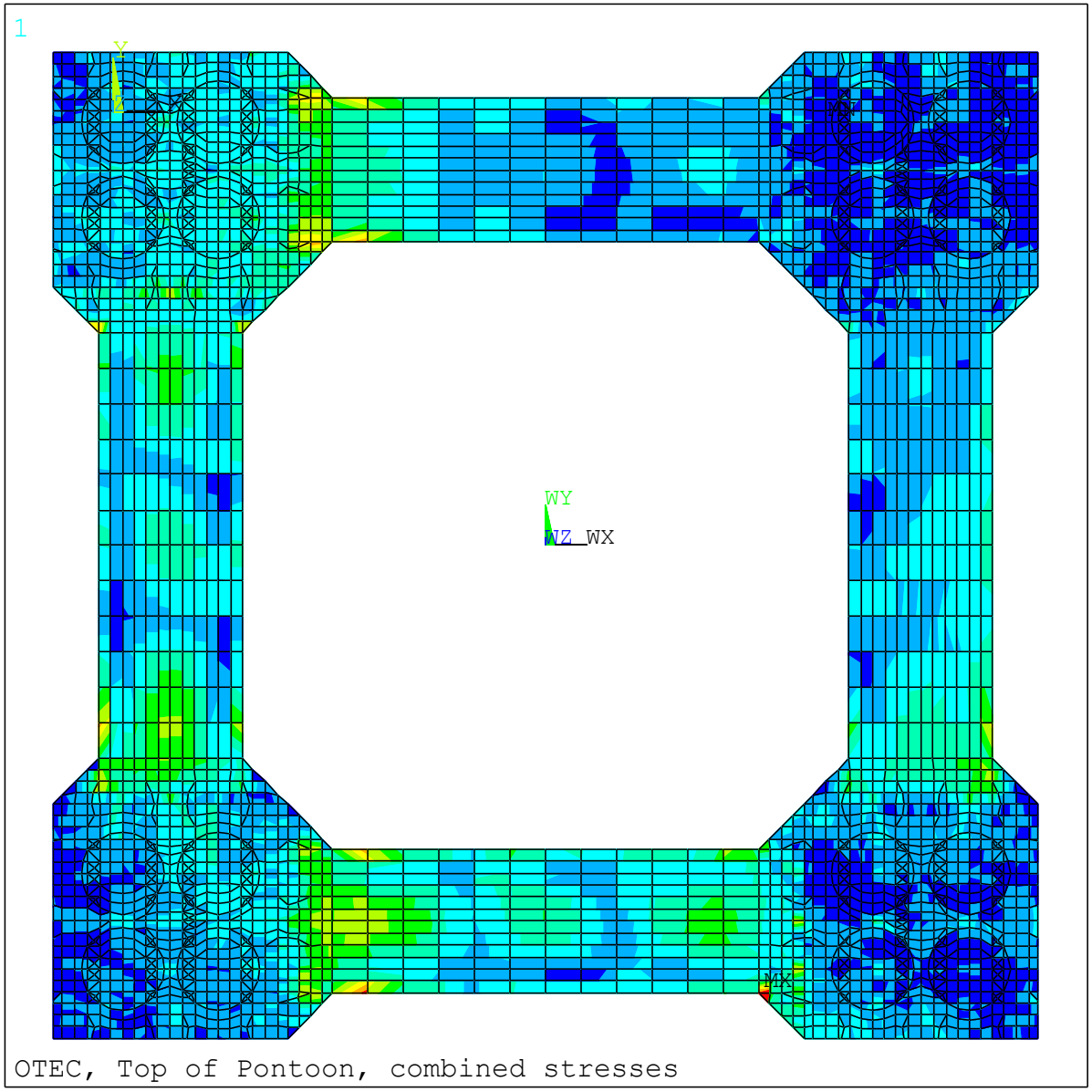


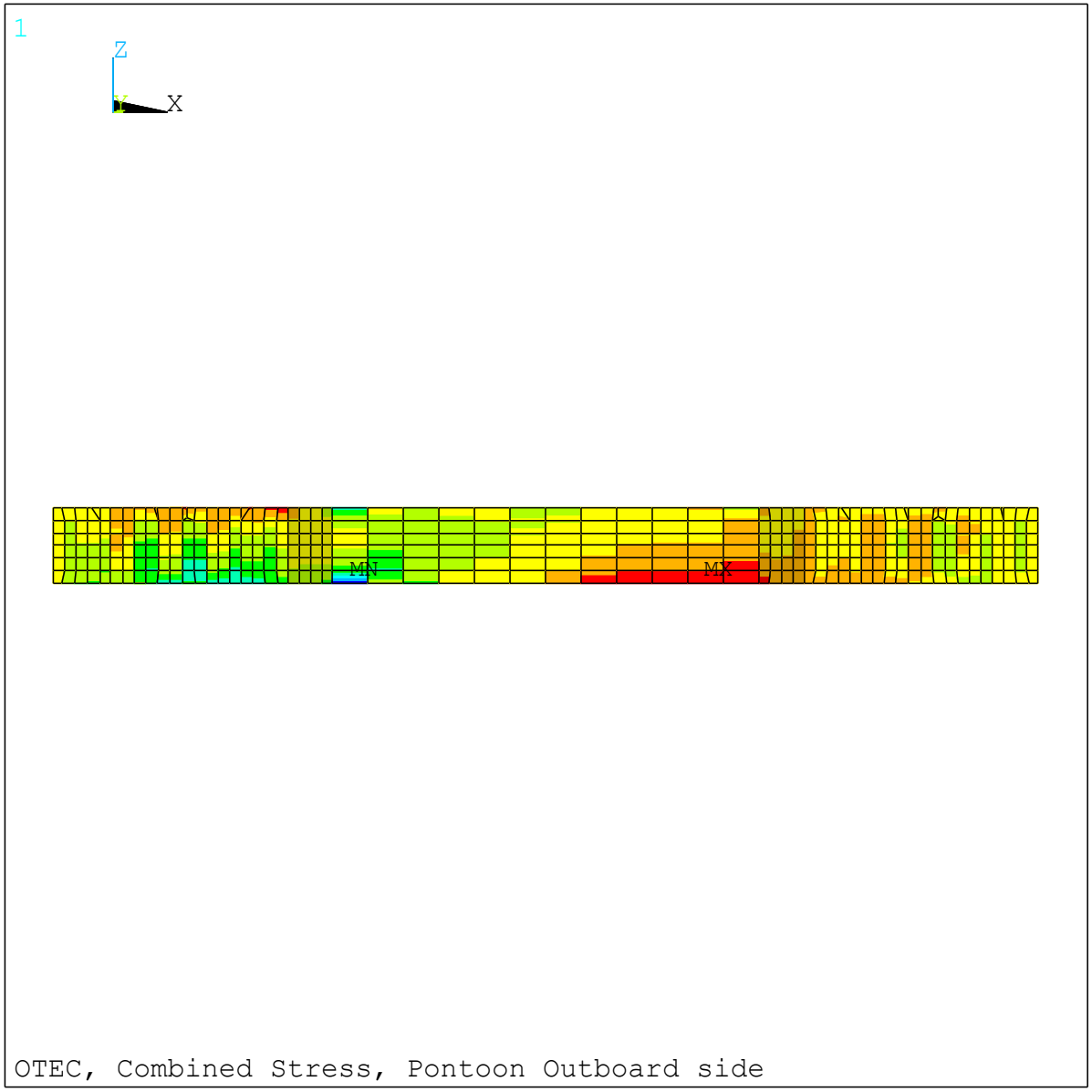
OTEC, Top of Pontoon, combined stresses

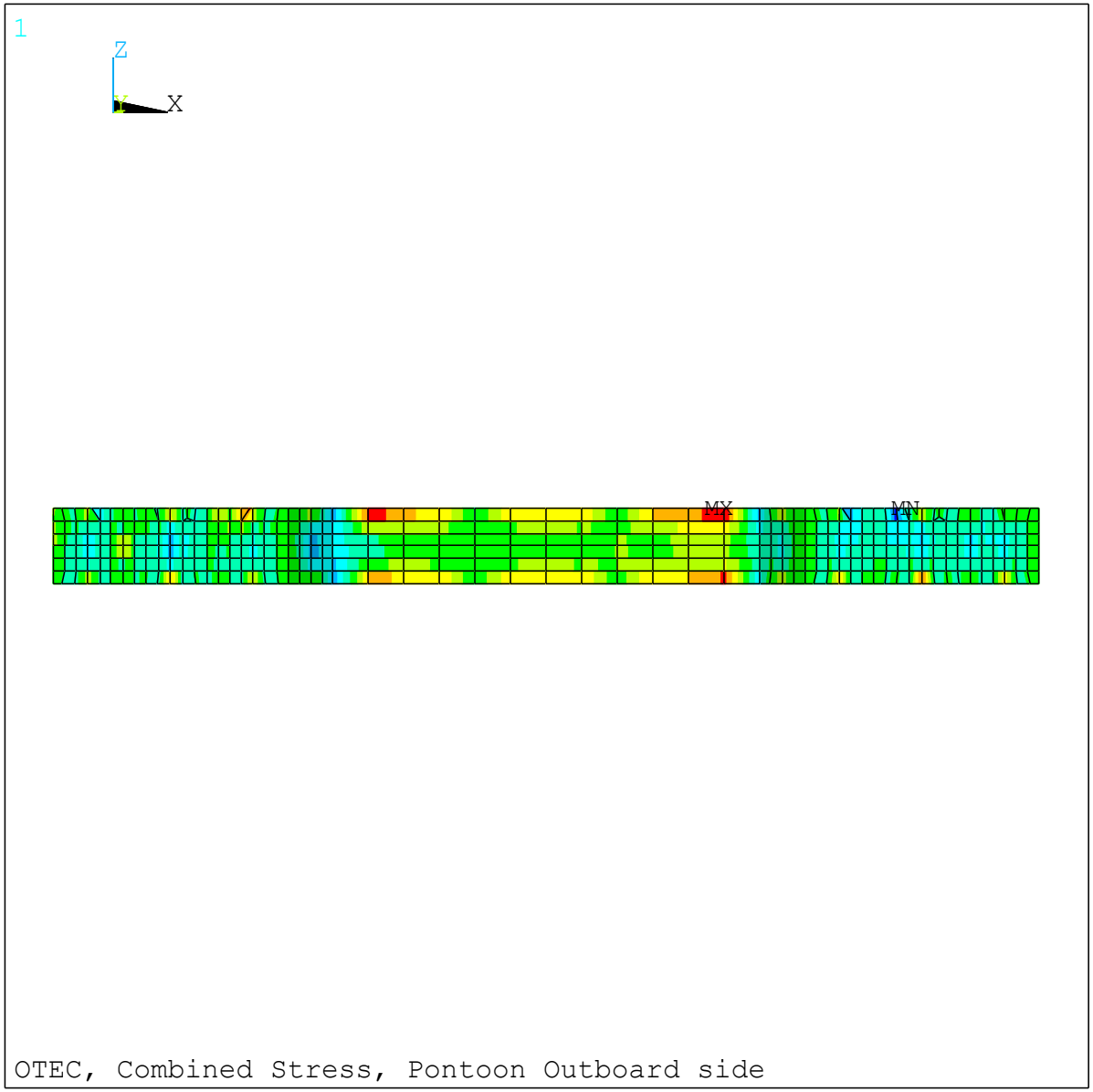
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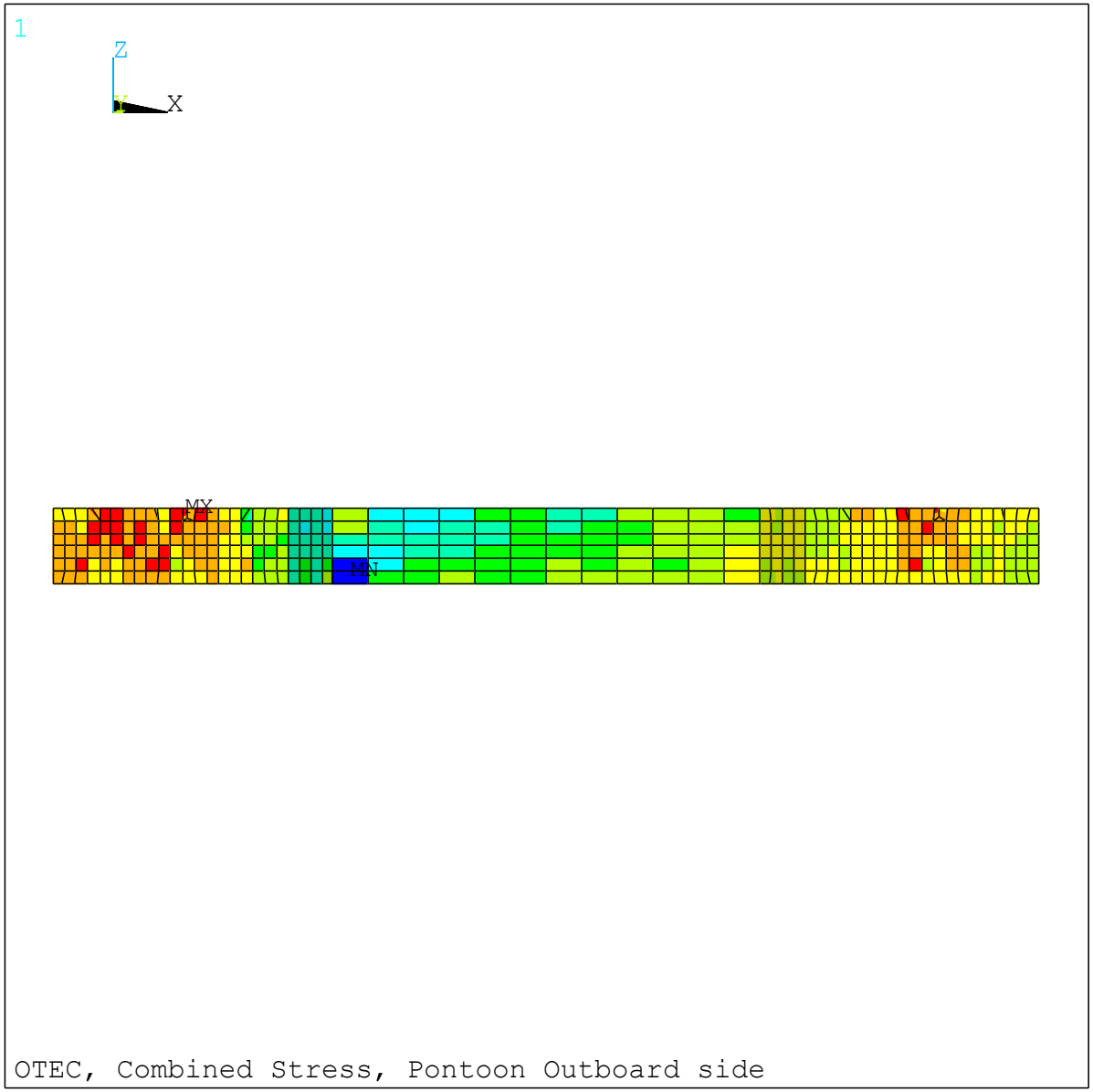
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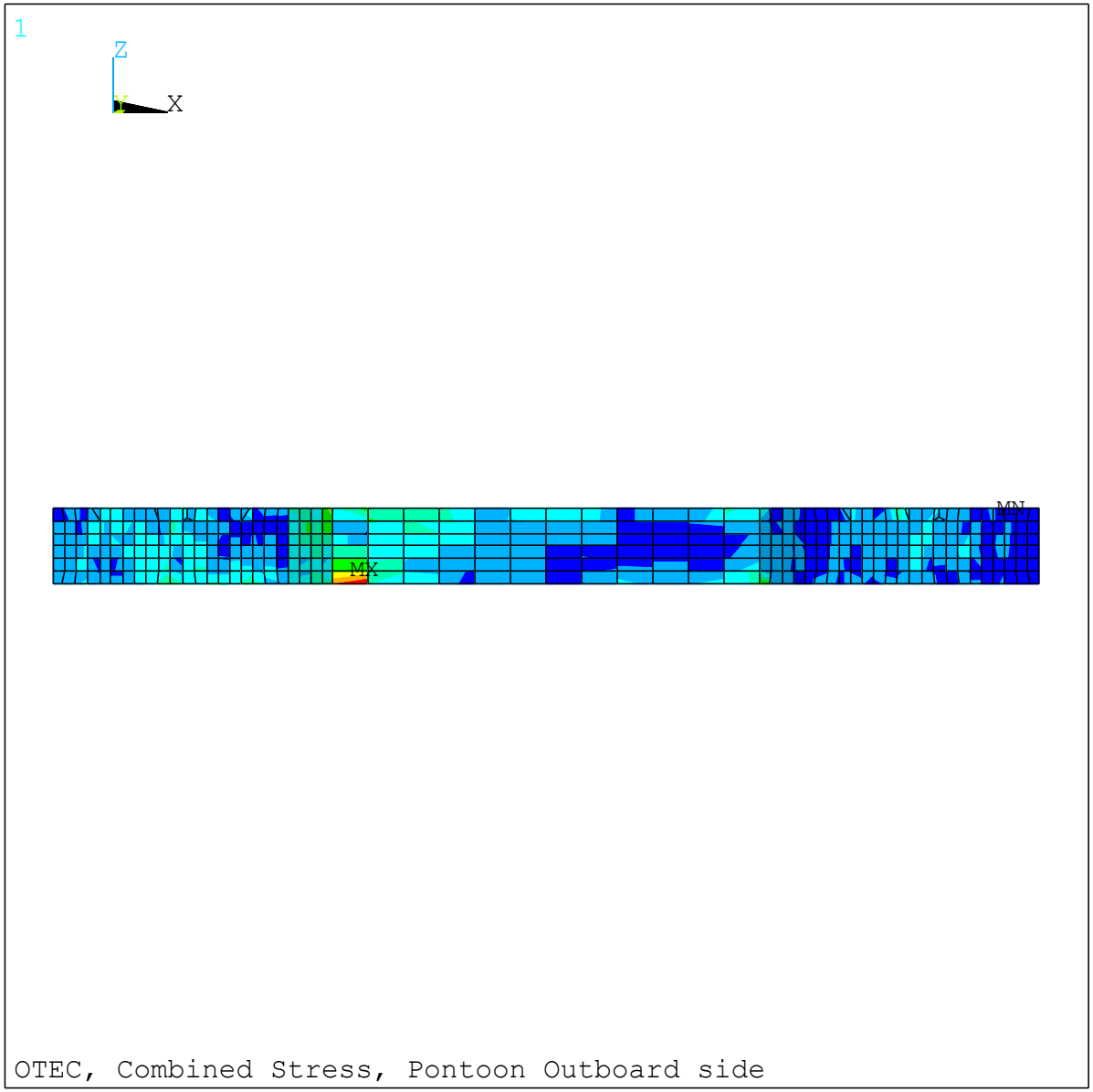

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OTEC, Top of Pontoon, combined stresses

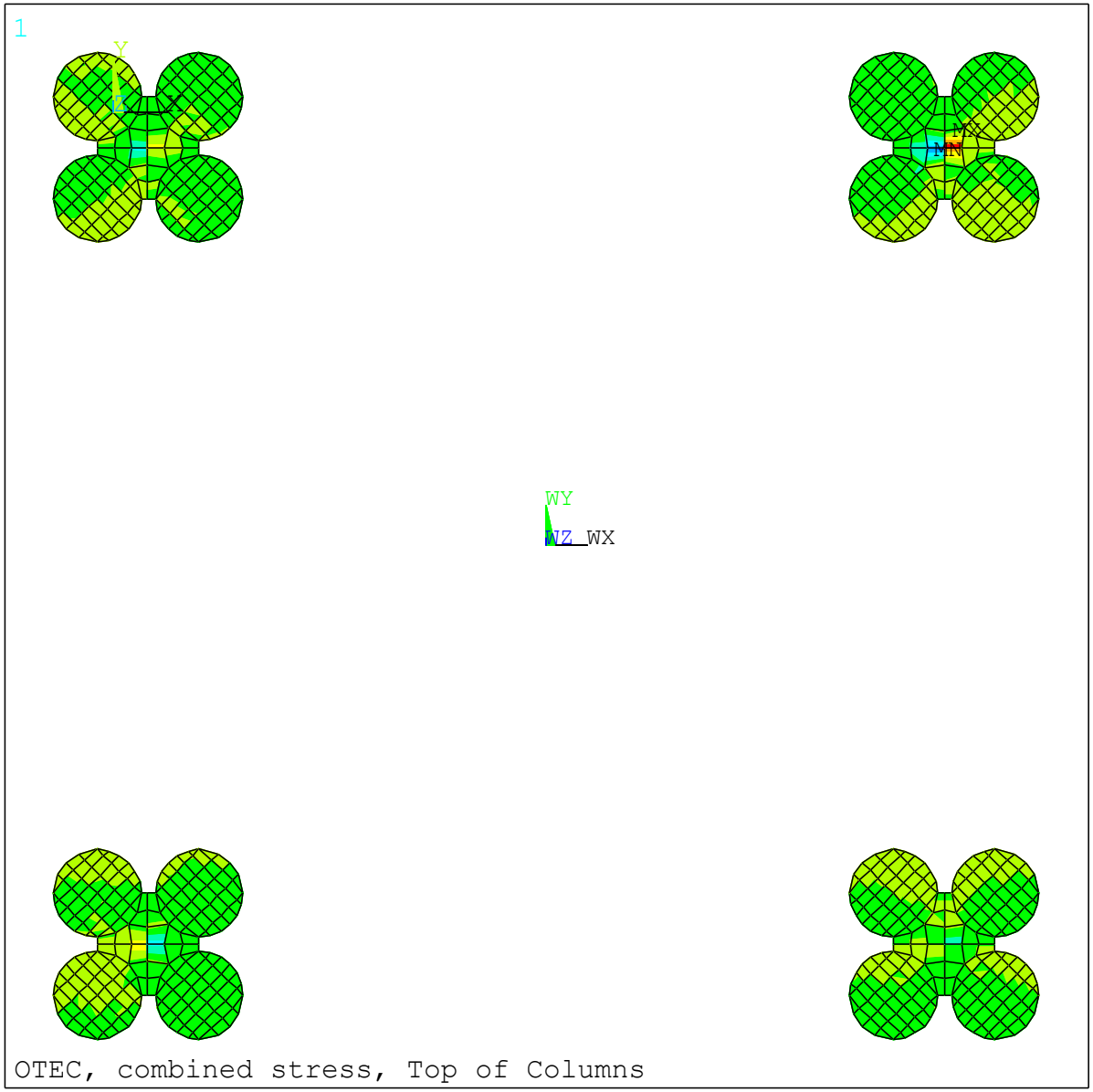

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OTEC, Top of Pontoon, combined stresses


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OTEC, Combined Stress, Pontoon Outboard side


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OTEC, Combined Stress, Pontoon Outboard side

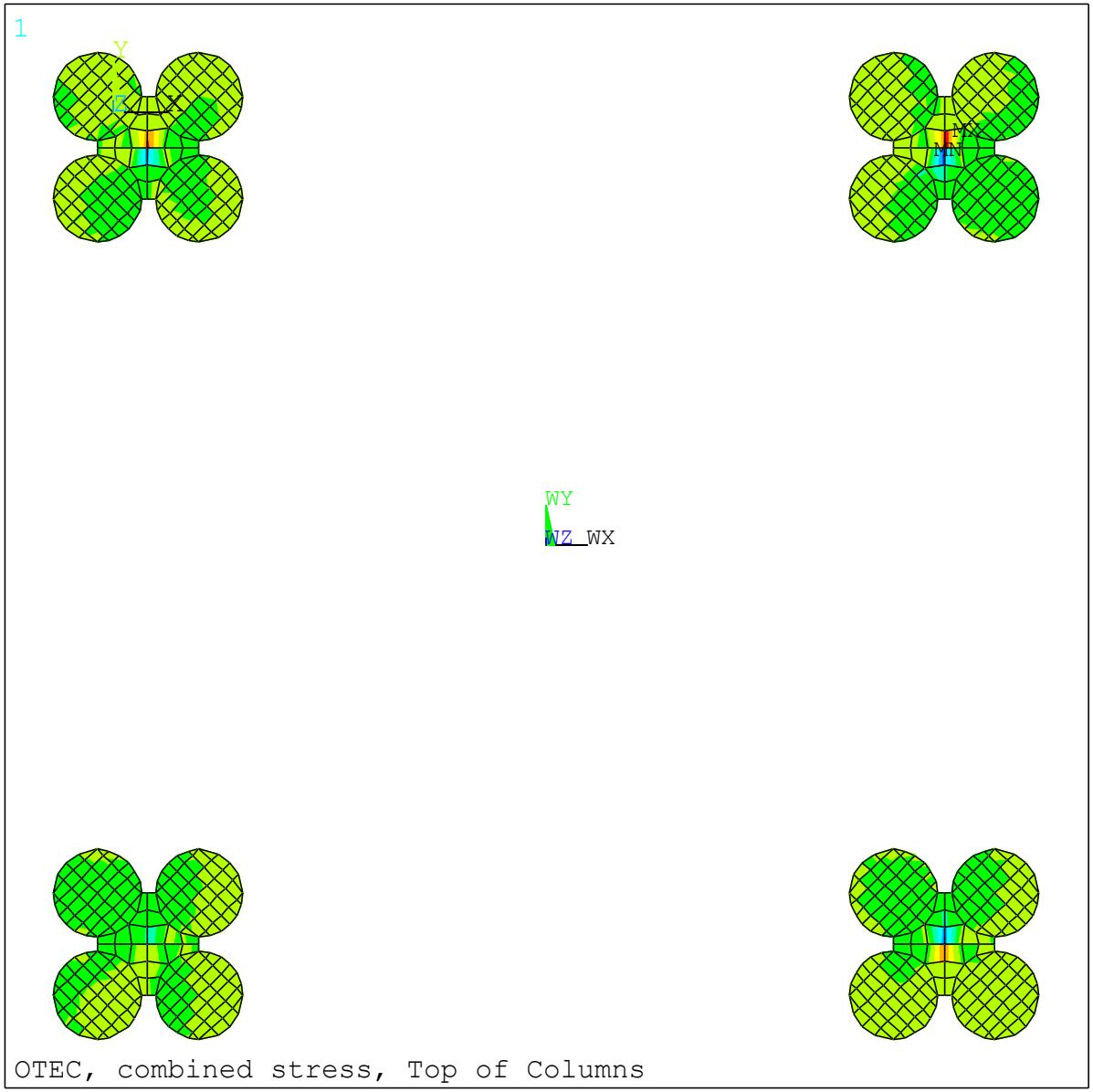

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OTEC, Combined Stress, Pontoon Outboard side


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OTEC, Combined Stress, Pontoon Outboard side



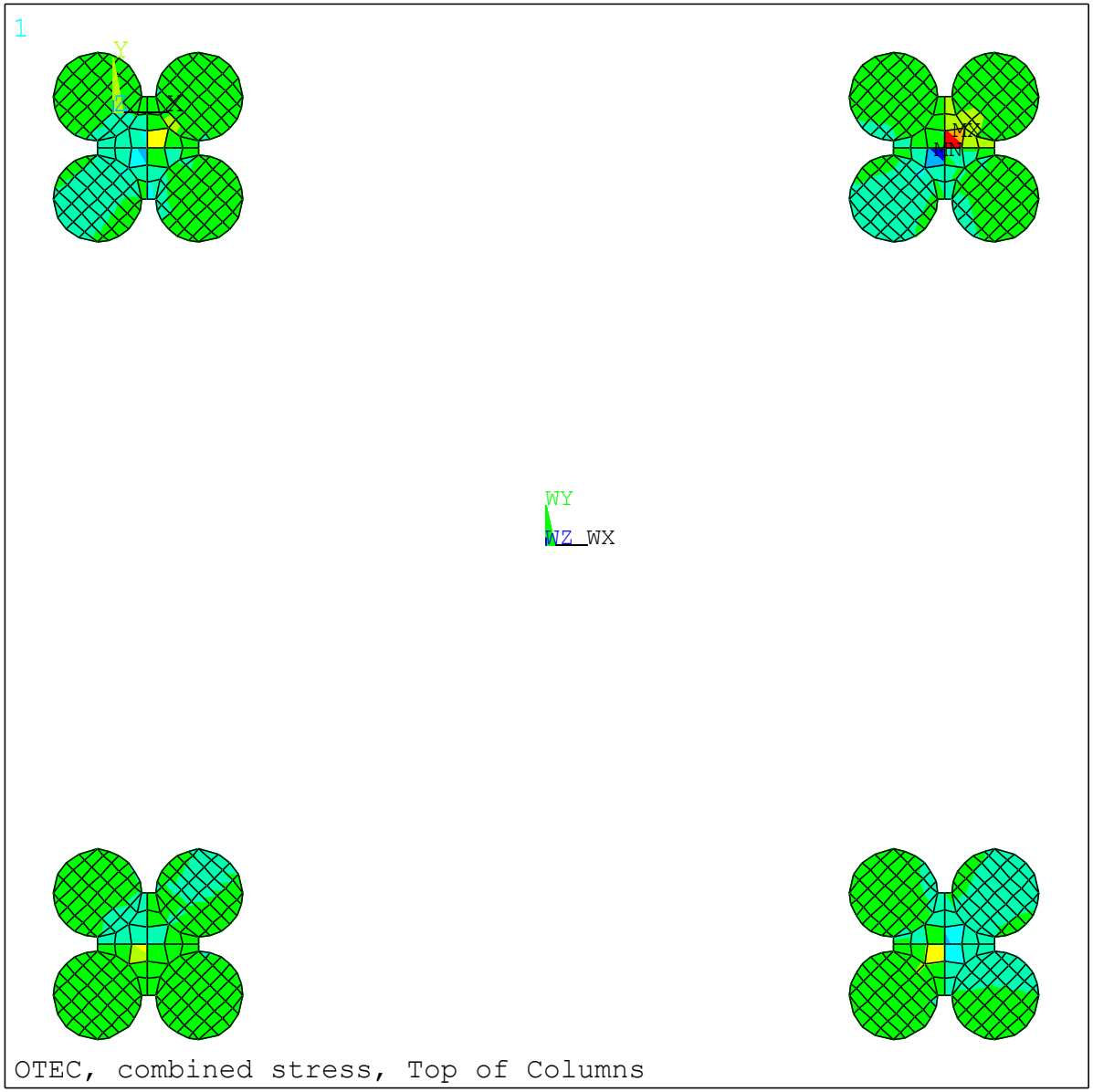
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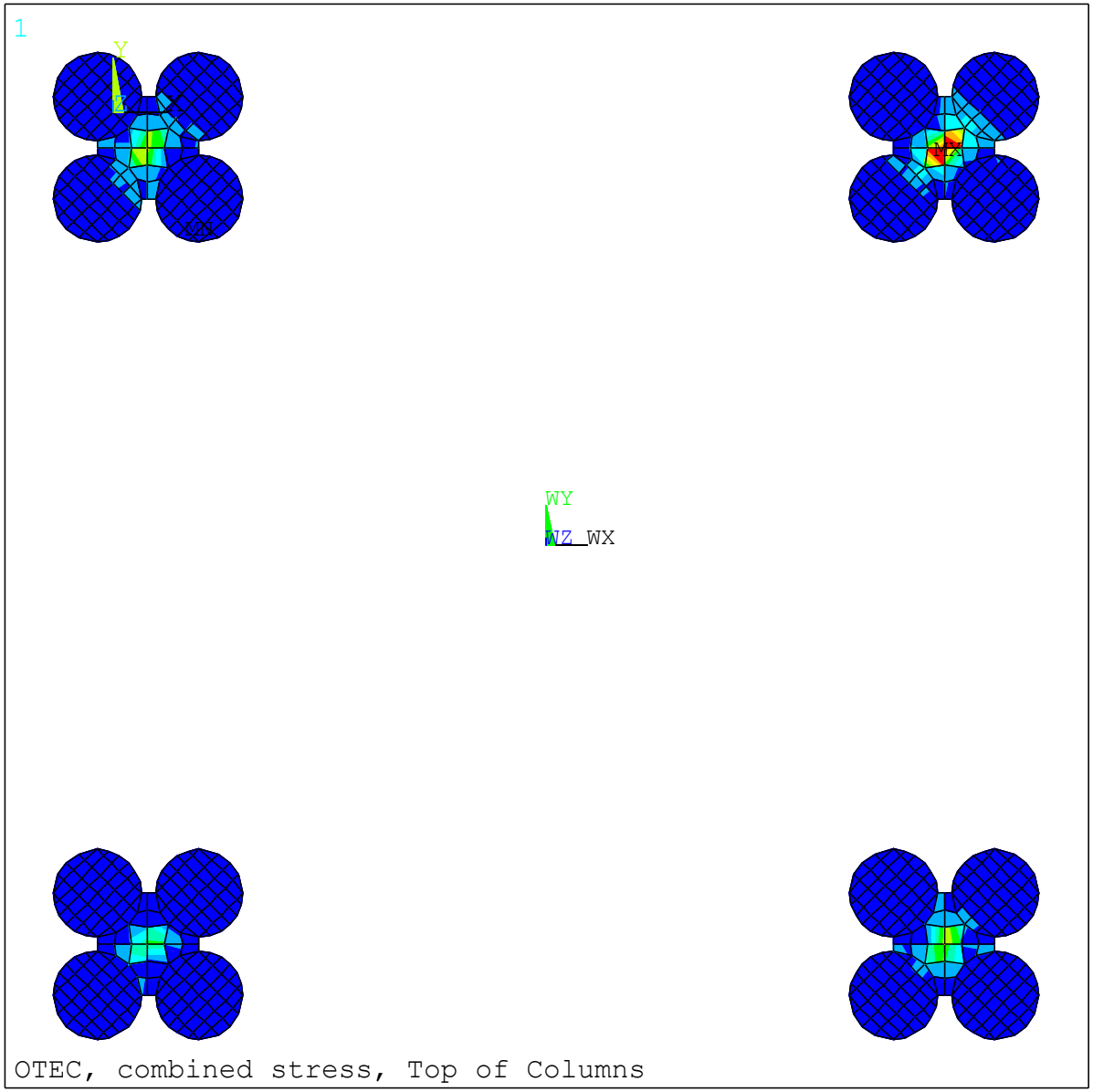
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NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-8
OTEC MCF Weight Report (HWD)
OTEC-2010-001

17 September 2010

Prepared for:

Naval Facilities Engineering Command
Naval Facilities Engineering Service Center (NFESC)
1100 23rd Avenue
Port Hueneme, CA 93043-4370
Attn: Mr. Brian Cable, Contracting Officer Representative

Prepared by:

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Manassas, VA 20110

Distribution Statement A: Approved for public release; distribution is unlimited

Weight Control Report

Ocean Thermal Energy Conversion (OTEC) MCF

for
John Halkyard & Associates



Document No.: HWD09-008-11-3002						
Rev. No.	**Rev. Date**	**Revision Description**	**Prepared By:**	**Checked By:**	**Approved By:**	**Client Approval**
Original	04/10/10	For issue to OTEC	D.Davies	J.Maher	J.Maher	

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1 SCOPE

Horton Wison Deepwater (HWD) has been tasked to configure the Multi-Column Floater (MCF) for support of a 10 mega-watt Ocean Thermal Energy Conversion (OTEC) plant to be installed offshore Hawaii in a water depth of 1100 meters.

Results of the preliminary weight estimates developed to perform global motions are presented in the following report. OTEC topside support structure and facility weights were provided by others and are not reported as part of this study.

Weights reported for the OTEC MCF 18 include hull structure and outfitting of the hull for marine operations. The weight calculations are extrapolated from previous MCF hull designs with adjustments estimated for features unique to OTEC.

HWD engineering systems are designed to allow use of modular design components and therefore rapidly create high quality concept drawings which contain lessons learned from previous product design cycles. Although the quality of the concept design is high, these drawings should not be confused with final FEED drawings.

The weight estimates are currently consistent with pre-FEED level estimates and will be updated along with the drawings as the design spiral progresses. The weights in the weight report have been used as the basis for the unit rate pricing that has been produced by HWD. A 5% weight contingency has been included on the majority of components at this time with higher percentages applied when designs are less defined.

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2 VESSEL SYSTEM DESCRIPTION

Horton Wison Deepwater has patented the Multi-Column Floater (MCF), a deep draft ring pontoon semisubmersible, with a vertically restrained well deck configured at its center. The advantage offered by the MCF is economical construction and low amplitude response to ocean environments. The hull is modified for support of the OTEC cold water pipe (CWP) and Remoras

The integrated hull and topsides provide a reduced offshore installation schedule. Large topside deck areas provide for installation and operation of the CWP fabrication plant while supporting OTEC power generation equipment and crew facilities. This system has been designed around concepts and components that will lead to robust technical designs for year round deployment.

The OTEC MCF-18 as shown in Figure 2-1 is a deep draft semi-submersible vessel with four columns positioned on 50 meter centers and a ring pontoon. Each column is built from four 5.5 meter diameter cylindrical cells. The pontoon is of standard flat stiffened plate construction providing support for the lower ends of the columns. The topside structure is a beam framed deck spanned between truss rows tied to the column foundations in the upper end of the MCF columns.

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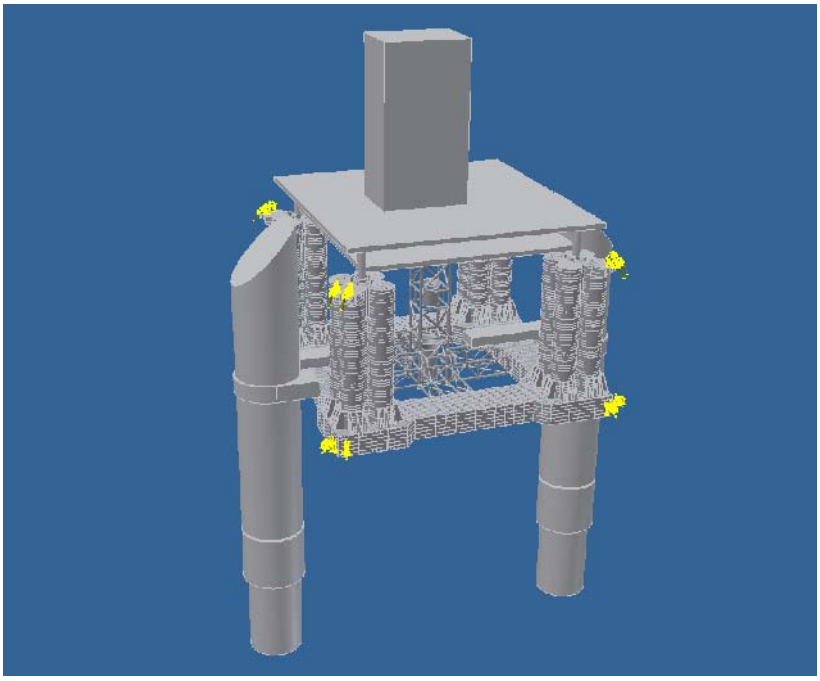


Figure 2-1 3D-View of the OTEC MCF 18

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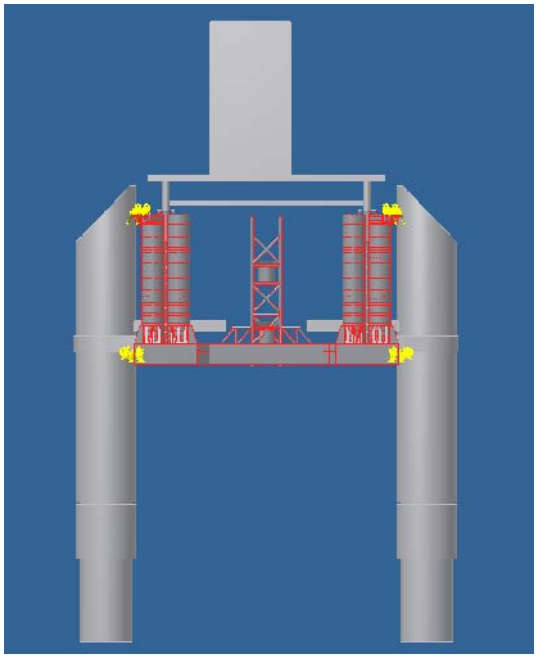


Figure 2-2 Elevation of the OTEC MCF 18

Figure 2-2 shows an elevation view of the OTEC MCF18. Four cells in each column are 31 meters long to provide a draft of 23 meters and a freeboard of 13 meters. The distance between two adjoined cells is 1 meter. Each cell is subdivided into three watertight compartments.

Draft and trim control uses a submersible pump placed in a caisson supported external to the column cells located above the variable ballast tank in the pontoon corners. The caisson is used for pulling and placing the submersible pump. The pump is supported on the bottom end of a pipe string placed inside the caisson. The pipe string functions as the discharge line when removing ballast water. Pumping seawater into the annulus between the wall of the caisson and the discharge pipe string provides ballast water to the variable ballast tank.

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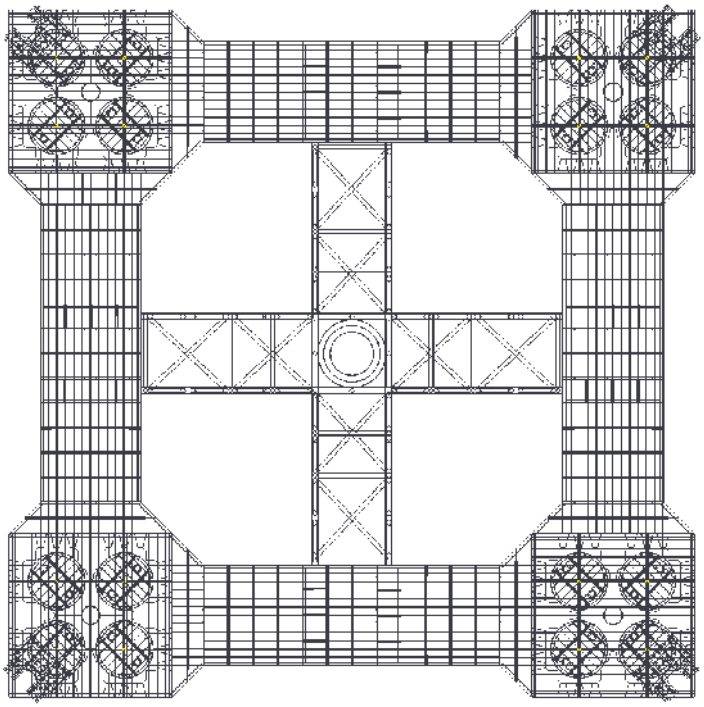


Figure 2-3 Top view and column layout of the OTEC MCF 18

Figure 2-3 shows a plan view of the OTEC MCF18. The pontoon serves as floatation during wet tow and is then flooded onsite for field installation. The pontoon remains flooded during the service life of the hull. The corners of the pontoon contain ballast tanks using sea water ballast, as described above, to provide a righting moment for trim correction and draft adjustment.

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3 WEIGHT SUMMARIES

Table 3-1 presents the estimated weight take-off of the OTEC MCF 18 hull structure with a breakdown of the major structural components. The coordinate system for the COG calculation is located on the vessels longitudinal and transverse centerline and the molded base line. Figure 3-1 shows nomenclature for hull.

Table 3-1 OTEC MCF 18 Hull Weight Summaries

OTEC MCF Structure Weight Take-off Summary					
Description	Calculated Weight	Estimated Weight	LCG	TCG	VCG
	(kg)	(kg)	(mm)	(mm)	(mm)
Pontoon	**1754412**	**1842133**	**0**	**0**	**2509**
Tank 10 Port	170087	178592	-24999	-25000	2496
Pontoon Port	268516	281942	0	-24999	2517
Tank 50 Port	170087	178592	24999	-25000	2496
Pontoon Forward	268516	281942	-25001	0	2517
Tank 10 Starboard	170087	178592	-24999	25000	2496
Pontoon Starboard	268516	281942	0	25001	2517
Tank 50 Starboard	170087	178592	24999	25000	2496
Pontoon Aft	268516	281942	24999	0	2517
Column Port Forward	**491463**	**516036**	**-25012**	**-25012**	**22171**
Cell 10 Port	123649	129831	-28269	-28269	22240
Cell 11 Port	122605	128735	-28250	-21750	22148
Cell 12 Port	122605	128735	-21750	-28250	22148
Cell 13 Port	122605	128735	-21750	-21750	22148
Column Starboard Forward	**491463**	**516036**	**-25012**	**25012**	**22171**
Cell 10 Starboard	123649	129831	-28269	28269	22240
Cell 11 Starboard	122605	128735	-28250	21750	22148
Cell 12 Starboard	122605	128735	-21750	28250	22148
Cell 13 Starboard	122605	128735	-21750	21750	22148
Column Port Aft	**491463**	**516036**	**25012**	**-25012**	**22171**
Cell 50 Port	122605	128735	21750	-28250	22148
Cell 51 Port	122605	128735	21750	-21750	22148
Cell 52 Port	123649	129831	28269	-28269	22240
Cell 53 Port	122605	128735	28250	-21750	22148
Column Starboard Aft	**491463**	**516036**	**25012**	**25012**	**22172**
Cell 50 Starboard	122605	128735	21750	28250	22148
Cell 51 Starboard	122605	128735	21750	21750	22149
Cell 52 Starboard	123649	129831	28269	28269	22240
Cell 53 Starboard	122605	128735	28250	21750	22148
Coldwater Pipe Support Truss	**212672**	**233939**	**0**	**3**	**8084**
Truss	212672	233939	0	3	8084
MCF Hull Structure Weight	**3932937**	**4140218**	**0**	**0**	**12627**

"Calculated Weight" is the weight as calculated from drawings.
"Estimated Weight" is the Calculated Weight with allowances added
Allowances are as presented in detailed weight take-off.

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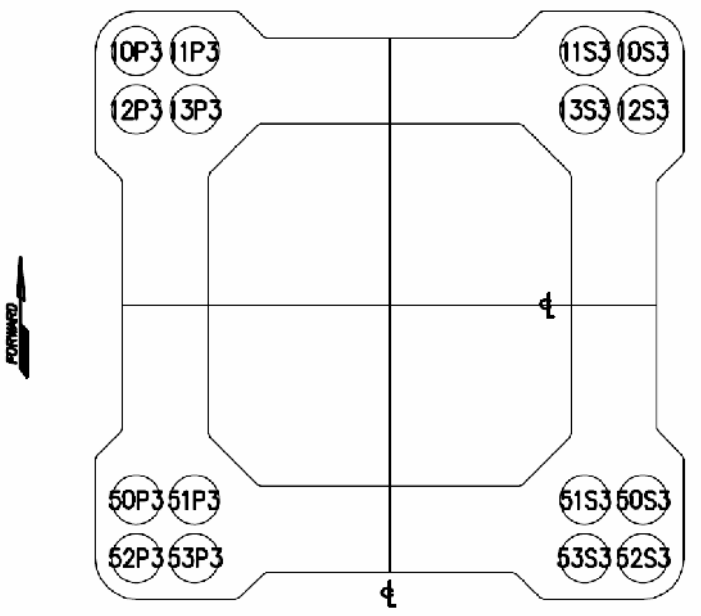


Figure 3-1 Column Layout

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Table 3-2 Outfitting Weight Summary

MCF - OTEC OUTFITTING							
Description	**Qty**	**Unit Wt.**	**Length**	**Wt**	**LCG**	**TCG**	**VCG**
		kg	m	kg	mm	mm	mm
Piping				**151157**			**24445.7**
Vent & Sounding				**36922**			**22591.7**
4" Vent / Sounding void 4	16	248.2		3972	0.0	0.0	31192.5
Striking plate	16	0.4		6	0.0	0.0	25629.0
Weld Neck Flange	16	7.3		117	0.0	0.0	36812.0
Blind Flange	16	7.5		120	0.0	0.0	36848.2
4" Vent / Sounding void 3	16	471.2		7539	0.0	0.0	26192.5
Striking plate	16	0.4		6	0.0	0.0	25629.0
Weld Neck Flange	16	7.3		117	0.0	0.0	36812.0
Blind Flange	16	7.5		120	0.0	0.0	36848.2
4" Vent / Sounding void 2	16	708.0		11328	0.0	0.0	20880.0
Striking plate	16	0.4		6	0.0	0.0	5004.0
Weld Neck Flange	16	7.3		117	0.0	0.0	36812.0
Blind Flange	16	7.5		120	0.0	0.0	36848.2
4" Vent / Sounding void 1A	16	819.5		13112	0.0	0.0	18380.0
Striking plate	16	0.4		6	0.0	0.0	4.0
Weld Neck Flange	16	7.3		117	0.0	0.0	36812.0
Blind Flange	16	7.5		120	0.0	0.0	36848.2
Ballast				**26438**			**22591.7**
Caisson	4	4726.0		18904	0.0	0.0	19243.0
Ballast pump	4	90.0		360	0.0	0.0	929.6
Air vent check valve	4	23.0		92	0.0	0.0	36.8
Check Valve	4	12.5		50	0.0	0.0	3828.0
Discharge string	4	1308.0		5232	0.0	0.0	20401.0
Ripouts (rupture disk)	20	90.0		1800	0.0	0.0	760.0
Marine systems				**87797**	0.0	0.0	**17868.4**
Seawater intake	1	9958.0		9958	0.0	0.0	20500.0
Overboard discharge	1	4361.0		4361	0.0	0.0	23300.0
scuppers and deck drain	4	2950.0		11800	0.0	0.0	35780.0
Skim pile	2	30476.0		60952	0.0	0.0	26815.0
Utility air	4	40.0		160	0.0	0.0	36300.0
Hydraulic piping	1	566.0		566	0.0	0.0	36054.0
Electrical				**11248.0**	0.0	0.0	**20500.0**
cable & tray	4	2812.0		11248	0.0	0.0	20500.0

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MCF - OTEC OUTFITTING							
Description	**Qty**	**Unit Wt.**	**Length**	**Wt**	**LCG**	**TCG**	**VCG**
		kg	m	kg	mm	mm	mm
Mooring				**589534.8**	0.0	0.0	**15077.5**
Chain Jack & stopper	8	3129.0		25032	0.0	0.0	36000.0
Fairlead	8	18500.0		148000	0.0	0.0	3048.0
Utility winch	4	181.0		724	0.0	0.0	36050.0
Chain locker	8	37285.0		298280	0.0	0.0	15333.0
Chain inboard of fairlead	8	9982.0		79856	0.0	0.0	20250.0
Tail Chain	8	355.7		2845	0.0	0.0	20500.0
Power Unit	2	3628.7		7257	0.0	0.0	36260.0
Control House	2	7983.0		15966	0.0	0.0	37100.0
Deck fitting	16	610.0		9760	0.0	0.0	36200.0
Supply boat mooring padeye	2	907.0		1814	0.0	0.0	29000.0
Corrosion protection				**243863.0**	0.0	0.0	**13332.4**
Paint	16	4252.0		68032	0.0	0.0	30500.0
Anodes	1	175831.0		175831	0.0	0.0	6690.0
Structure Outfitting				**1001242.3**	0.0	0.0	**20764.3**
Hull markings	4	907.0		3628	0.0	0.0	24000.0
Ladders	16	1242.3		19876	0.0	0.0	20704.0
Manway top of column	32	144.4		4622	0.0	0.0	36177.0
Manways	96	270.6		25976	0.0	0.0	15767.0
Fnd Column	32	7810.0		249920	0.0	0.0	7065.0
Interstitial Decks	16	4990.0		79840	0.0	0.0	28500.0
Fnd Chain Jack & Stopper	8	12474.0		99792	0.0	0.0	36000.0
Fnd fairlead	8	19685.0		157480	0.0	0.0	3200.0
Fnd Topside	4	82282.0		329128	0.0	0.0	32940.0
Boat landing	1	30980.0		30980	0.0	0.0	23746.0
Outfitting Weight Total				**1997045.33**	**0.0**	**0.0**	**18455.2**

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NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-9
OTEC MCF Global Performance Report (HWD)
OTEC-2010-001

17 September 2010

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Global Performance Report

Ocean Thermal Energy Conversion (OTEC) MCF

for
John Halkyard & Associates



Document No.: HWD09-008-11-3001						
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1 EXECUTIVE SUMMARY

1.1 Overview

Horton Wison Deepwater (HWD) was awarded a contract from John Halkyard Associated to perform the initial design, configuration, and global performance analysis as well as execution plan for the Multi Column Floater (MCF). MCF has been designed primarily for offshore oil and gas application. For Ocean Thermal Energy Conversion platform, the MCF can be used with minor modification.

The major difference between the OTEC MCF and offshore oil MCF is the Cold Water Pipe (CWP) hanging at the keel of the MCF. The mass of CWP, including the entrained water inside the pipe, is comparable to the mass of the MCF. For offshore oil application, there is no CWP but risers with much lighter mass.

This report presents the assumptions, methods and results of the global performance and mooring analysis for the OTEC MCF. Global performance establishes the overall motion response of the platform and provides design loads for other disciplines. The mooring design has been checked by using ABS and API codes and compliance with these codes is demonstrated in this report. Furthermore, the maximum design loads, such as maximum tensions at the fairlead, are provided for mooring equipment and anchor design.

In addition, there is a second report, titled “Execution Plan – Ocean Thermal Energy Conversion (OTEC) MCF” and written by HWD, which review the OTEC MCF in terms of fabrication, transportation and cost.

The time domain simulation program HARP/CHARM3D [Ref. 1] is used to calculate the MCF motions, mooring tension and anchor load design. The analysis is carried out for three phase of OTEC MCF life; pipe fabrication, pilot test and production. As expected, the production phase governs the MCF offset, heel, heave, and topside acceleration as well as mooring line tensions except for the offset during broken line condition. During the pilot test, MCF with one line broken has 294 meter of offset, which is almost three times larger than during the production phase.

During the production phase, the mooring system used in this analysis is based on an industry proven 8 chain-polyester-chain configurations, but during the pipe fabrication and pilot phases only 4 moorings are installed.

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1.2 Study Summary

The main results are summarized as follows:

Natural Periods

MCF natural periods during pipe fabrication and production phase are calculated from free decay simulations. Heave natural periods are in the range of 20 and 25 seconds, while roll and pitch are in the range of 19 and 28 seconds. Summary of the natural periods are presented in Table 1-1.

Table 1-1 MCF Natural Periods

Natural Periods		Pipe Fabrication	Production
Motion	**Unit**	**Hull**	**Hull**
Surge	sec	112.0	115.5
Sway	sec	124.0	115.5
Heave	sec	25.0	20.0
Roll	sec	27.7	26.7
Pitch	sec	27.0	18.8
Yaw	sec	72.7	51.3

Motion Response

Summary of MCF hull motions during pipe fabrication, pilot test and production phases are shown in Figures 1-1 through 1-3, respectively. Therein, offset is defined as vector summation of surge and sway motions, while heel is defined as vector summation of roll and pitch. Offset is measured in terms of nominal water depth (1,000 m), heave is in meter and heel is in degree.

The maximum offsets of MCF hull at the mean water level (MWL) in 10 year Sea and 10 year Swell during pipe fabrication are 1.45% and 1.08% of water depth, respectively. The maximum heel angle and heave ranges are about 2.18 degree and 1.86 meter, respectively.

During pilot test, the maximum offset of MCF hull at MWL in the intact and broken line conditions and 25 year of cyclone are 2.0% and 29.4% of water depth, respectively. The maximum heel angle in intact and broken line conditions is 1.91 and 2.26 degree, respectively, while the heave ranges in intact and broken line conditions are about 1.36 m and 1.95 m, respectively.

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During production phase, the maximum offset of MCF hull at MWL in the intact and broken line conditions and 100 year of cyclone are 5.51% and 10.75% of water depth, respectively. The maximum heel angle both in intact and broken line conditions are 3.9 and 4.06 degree, respectively, while the heave ranges both in intact and broken line conditions is about 4.3 m.

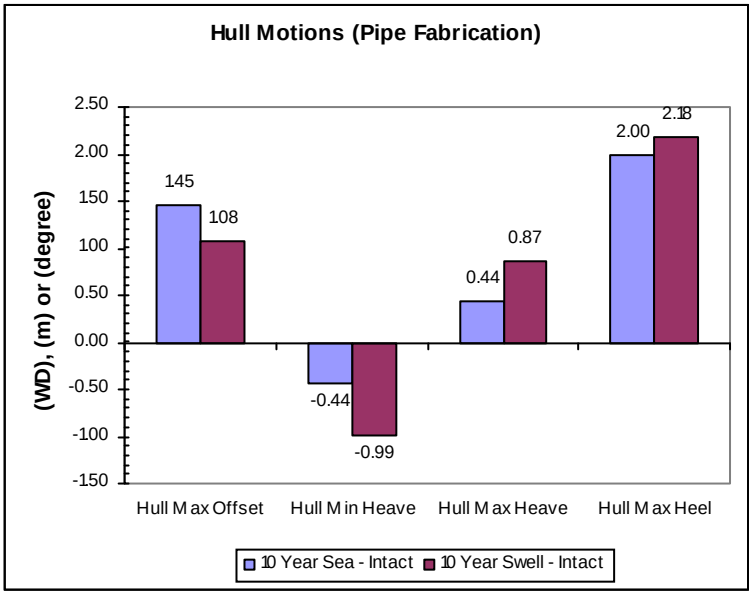


Figure 1-1 Summary of Motions during Pipe Fabrication

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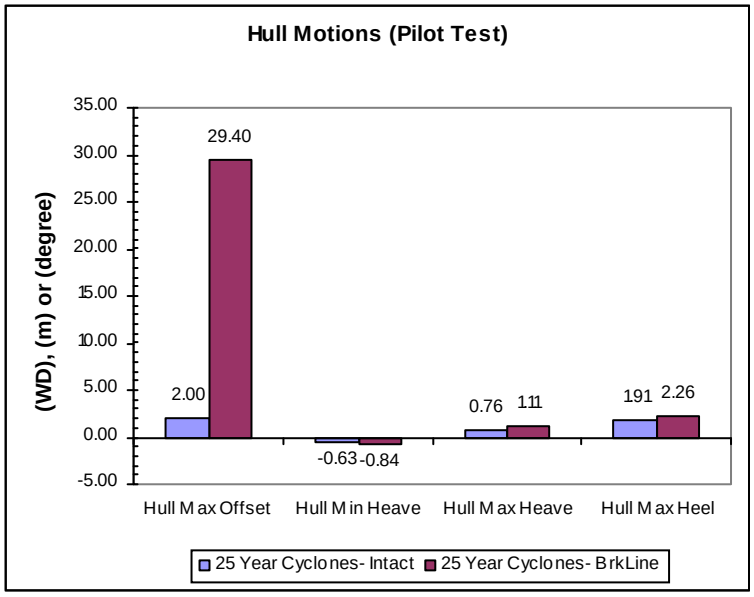


Figure 1-2 Summary of Motions during Pilot Test

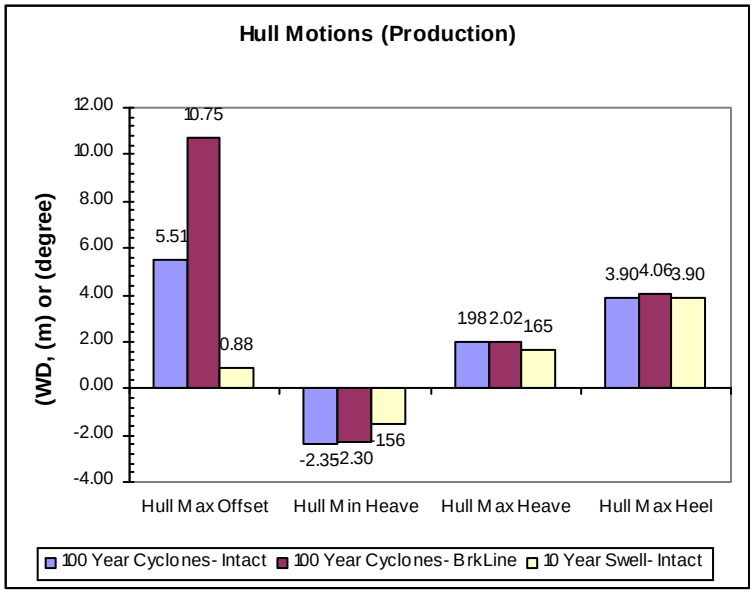


Figure 1-3 Summary of Motions during Production

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Mooring Tension

Summary of mooring tensions during pipe fabrication, pilot test and production phases are shown in Figures 1-4. The maximum mooring tensions for the chain section in the intact and broken line condition are 0.44 and 0.73 of the breaking strength, respectively, while for polyester section are 0.37 and 0.63 of the mean breaking loads, respectively. All maximum tension occurred during production phase.

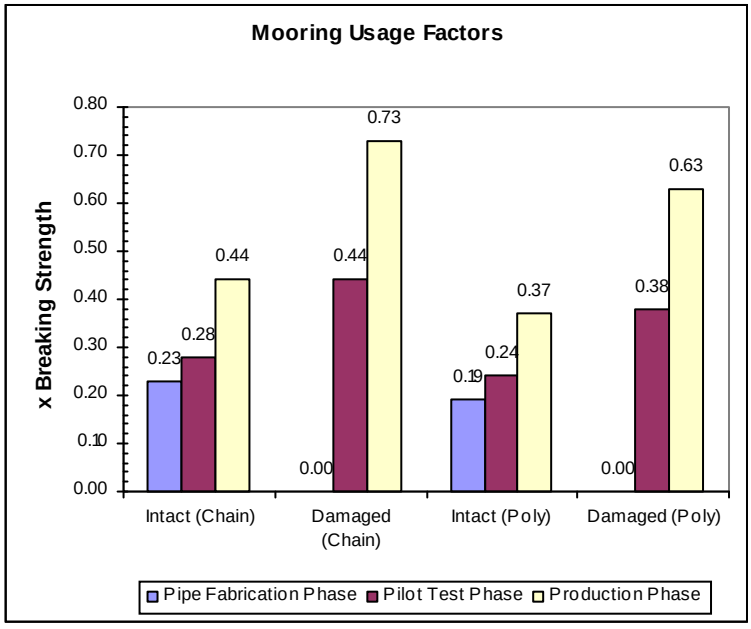


Figure 1-4 Summary of Mooring Tensions

Topside Acceleration

Including the gravity component, the maximum lateral acceleration at the topside during pipe fabrication, pilot test and production phases are shown in Figures 1-5. For pipe fabrication phase, the maximum lateral acceleration is about 0.09 g while during production phase is about 0.19 g.

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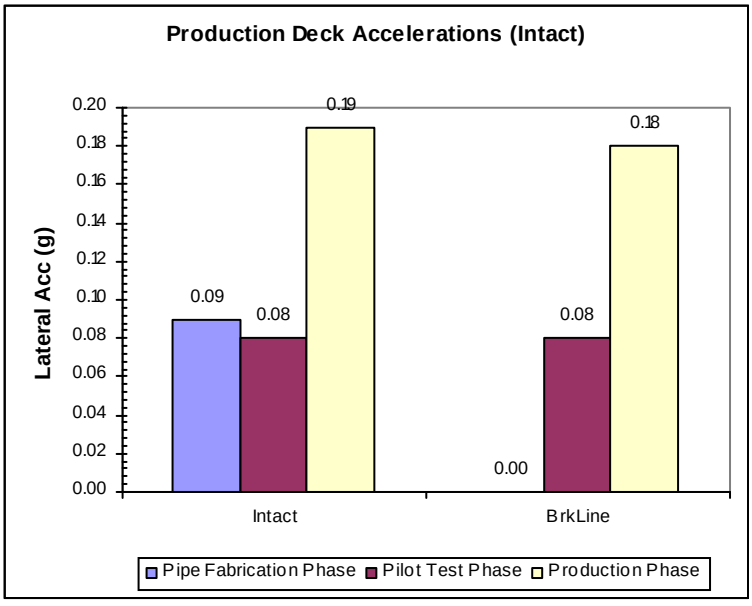


Figure 1-5 Summary of Topside Acceleration

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2 INTRODUCTION AND OBJECTIVES

2.1 Vessel System Description for Deepwater Oil and Gas Application

Horton Wison Deepwater has patented the deepwater Multi Column Floater (MCF) drilling and production deep draft ring pontoon semisubmersible, with a vertically restrained well deck (air buoyancy can to support riser) configured in the center of the MCF. The vertically restrained well deck (similar to a tension leg spar) independently supports and provides tension for the import flowline and export pipeline risers. The vertical risers are installed by a pipe handling rig on the MCF. These risers are installed one at a time as needed. The diameter and wall thickness of each riser can be selected later in the life of the facility. This aspect provides great flexibility for the riser system.

The integrated hull and topsides facilitate a relocatable platform which can produce oil and gas, as well as decrease the high drilling and well completion costs associated with field development in today's deepwater fields. This system has been designed around concepts and components that will lead to robust technical designs that allow the unit to stay connected with risers, year round.

The vertically restrained well deck is the platform for the tubing risers, export pipelines, and the riser jumpers. Therefore the riser loads that are traditionally carried by the floating production platform are now carried independent of the hull. The MCF hull payload capacity is not burdened with the additional riser loads.

The MCF as shown in Figure 2-1 to 2-3 is a deep draft semi-submersible vessel with four columns and a ring pontoon (base). Each column is built from four cylindrical tubes. The base is of standard stiffened plate construction and connects the lower ends of the columns. The topside of the vessel is designed as a module-support-frame that can accommodate payload modules inside its space frame

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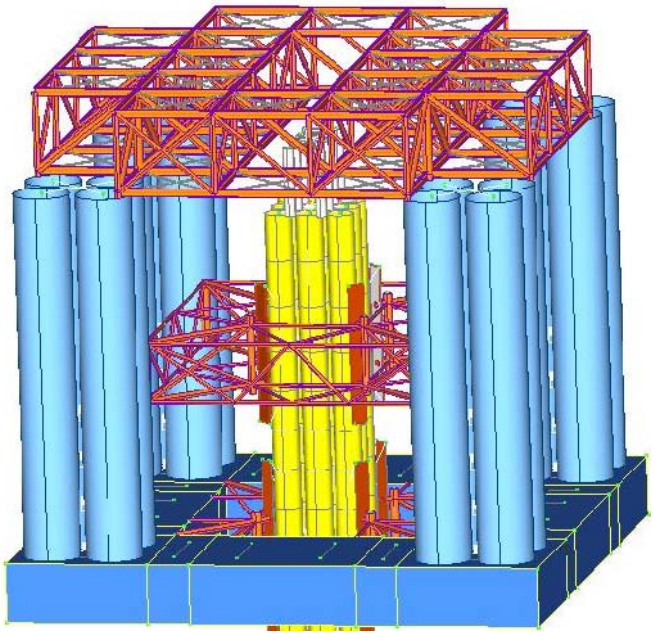


Figure 2-1 3D-View of the MCF for Deepwater Oil and Gas Application

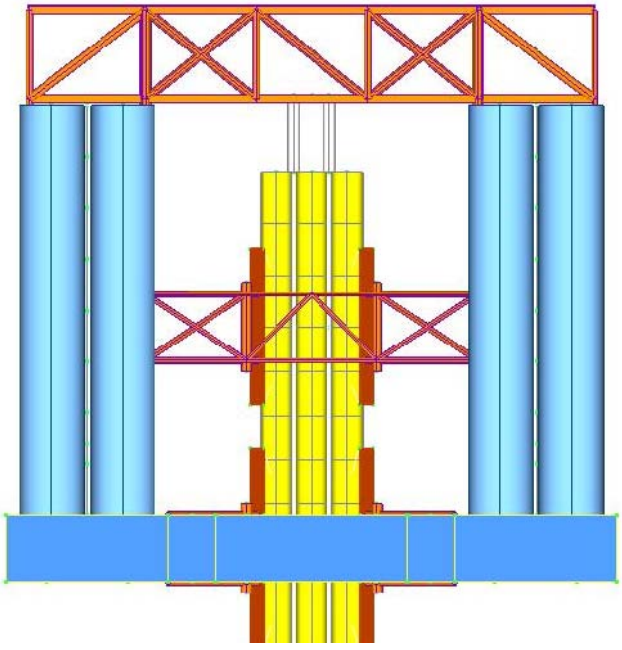


Figure 2-2 Elevation of the MCF for Deepwater Oil and Gas Application

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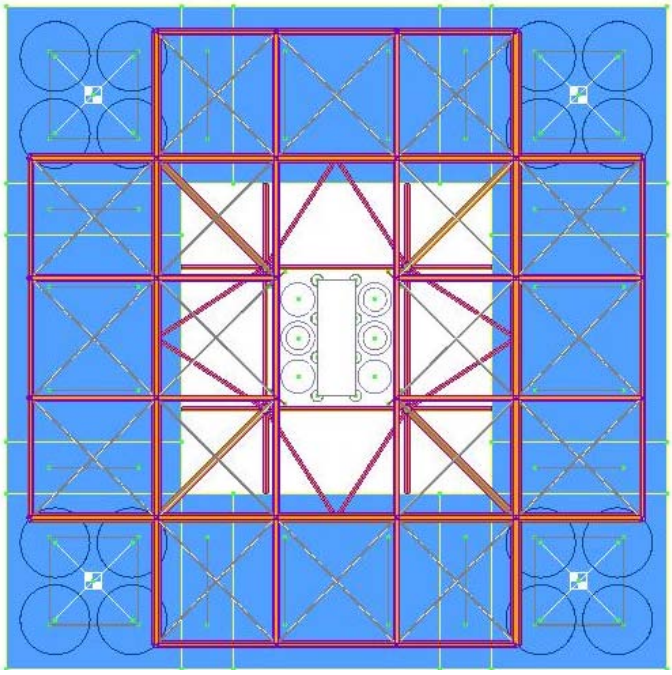


Figure 2-3 Top view and column layout of the MCF for Deepwater Oil and Gas Application

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2.2 Vessel System Description for OTEC MCF

MCF for OTEC application is similar to that of deepwater oil and gas. The obvious different is on the center of the hull. Instead of having the vertically restrained well deck, the OTEC MCF has the Cold Water Pipe and Remora as shown in Figure 2-4. Detail description of the OTEC MCF can be found in Ref. 2.

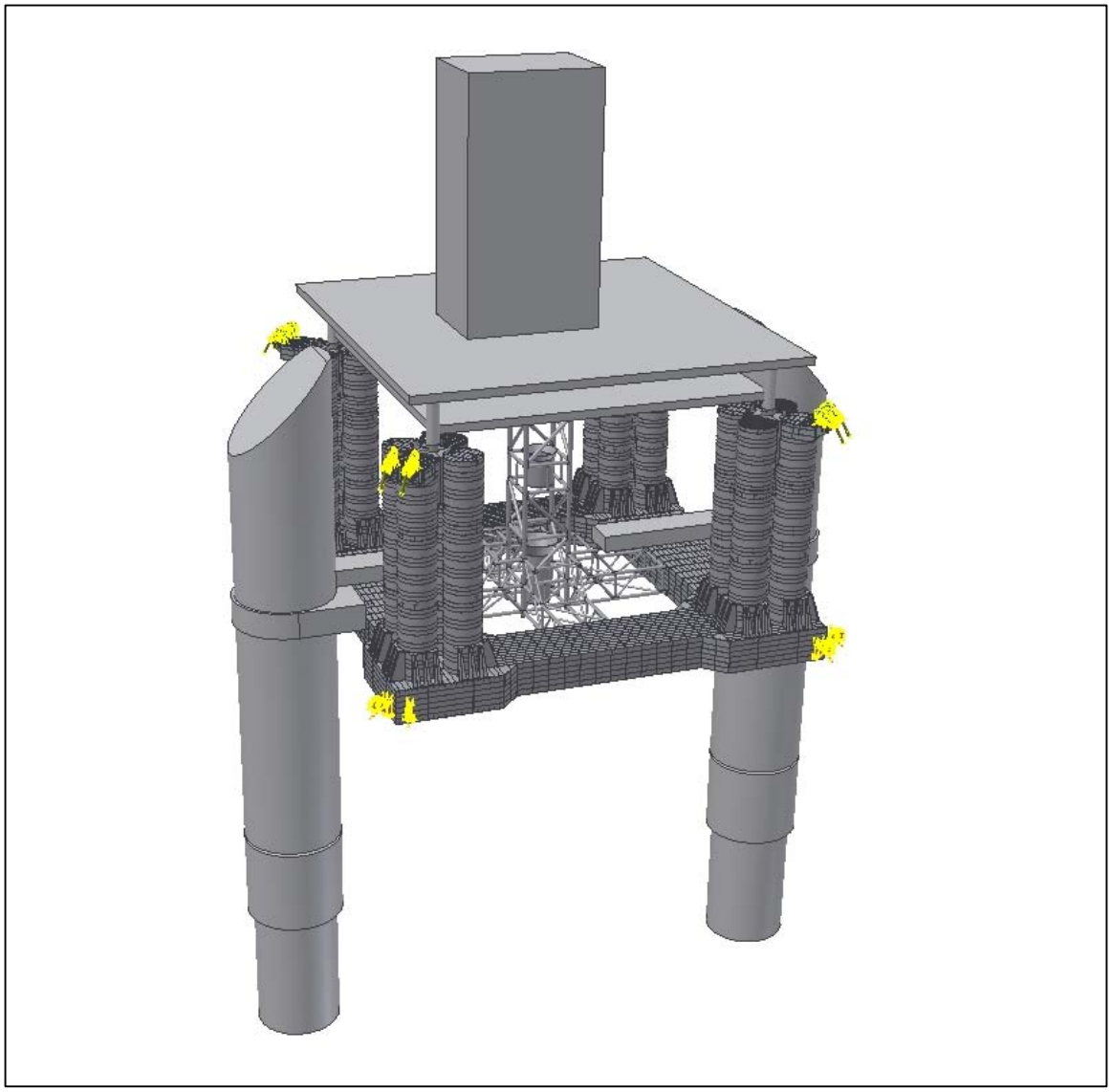


Figure 2-4 3D-View of the MCF for OTEC Application

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2.3 Objectives

The objective of the work described in this report is to document the global performance and mooring analysis that demonstrates the design adequacy of the Multi-Column Floater system to withstand the design environments with regard to:

- Maximum offset and heel
- Maximum mooring line tensions
- Maximum accelerations at topside

The overall scope of the work is to develop data required for the design of the Multi-Column Floater (MCF) configuration by analyzing the MCF and its components as a complete system, including the following subsystems:

- MCF hull (structure, variable ballast, entrained water)
- Topsides
- Mooring system
- Cold Water Pipe
- Remoras

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3 DESIGN BASIS AND ASSUMPTIONS

3.1 Design Input Data

The design criteria and key input data used in the hull and mooring sizing for the OTEC MCF are summarized in Tables 3-1 and 3-2. OTEC MCF is designed to have three different configurations (phase) during life span:

- Pipe Manufacturing
- Pilot Test
- Production

During pipe manufacturing, no remoras are installed and the hang-off point of CWP is assumed to be 10 meter above the mean water level. During pilot test, one remora is installed, the pipe manufacturing equipments are removed from the topside and the hang-off point of CWP is assumed to be 20.5 meter below the mean water level. During production, the OTEC MCF configuration is similar to the pilot test with one additional remora being added to the system.

Table 3-1 Design Criteria during Pipe Manufacturing

MCF Sizing Criteria - with Pipe Mfg.			
		Value	Units
Topsides			
	Weight	4222.0	mt
	CG from water line	19.3	m
Remora			
	Remora A Weight	NA	mt
	CG from water line	NA	m
	Remora B Weight	NA	mt
	CG from water line	NA	m
Cold Water Pipe (Installed)			
	Tower and Pipe Weight	352.0	mt
	Hang-of point from water line	10.0	m

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Table 3-2 Design Criteria during Production

MCF Sizing Criteria - without Pipe Mfg.			
		Value	Units
Topsides			
	Weight	3852.0	mt
	CG from water line	19.3	m
Remora			
	Remora A Weight	5317.0	mt
	CG from water line	-36.9	m
	Remora B Weight	5317.0	mt
	CG from water line	-36.9	m
Cold Water Pipe (Installed)			
	Pipe and Clump weight	352.0	mt
	Hang-of point from water line	-20.5	m

3.2 Metocean Criteria

The global performance analysis of the OTEC MCF was performed based on the environmental data listed on the design basis document [Ref. 3]. Tables 3-4 and 3-5 show environmental data used in this study. Winds, waves and currents are assumed to be co-linear and Hs for 100 year cyclone may be reduced to 5 m for direction (toward) 180-240 degrees due to shielding (see Figures 5-1 and 5-2 for coordinate system)

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Table 3-3 Metocean Criteria – Extreme Events

Description	100 yr Cyclone		25 yr Cyclone		Max Current	
Wave (JONSWAP)						
Hs (m)	10.20		4.30		1.50	
Tp (sec)	12.8		10.6		14	
Wave Crest (m)	NA		NA		NA	
Peakedness Parameter	2		2		6	
Water Level						
Storm Surge (m)	NA		NA		NA	
Tidal Amplitude (m)	NA		NA		NA	
Wind (NPD)						
V (1hr@10 m) - m/s	33.80		13.70		8.00	
Direction from Wave (deg)	0		0		0	
Current	Depth (m)	Vel (m/s)	Depth (m)	Vel (m/s)	Depth (m)	Vel (m/s)
	0.00	1.40	0.00	0.72	0.00	0.88
	-50.00	1.00	-50.00	0.72	-50.00	0.77
	-100.00	0.33	-100.00	0.49	-100.00	0.72
	-150.00	0.33	-150.00	0.49	-150.00	0.70
	-350.00	0.20	-350.00	0.30	-350.00	0.33
	-800.00	0.18	-800.00	0.28	-800.00	0.33
	-1000.00	0.15	-1000.00	0.23	-1000.00	0.29
Direction from Wave (deg)	0.00		0.00		0.00	

Table 3-4 Metocean Criteria – 10 Year Events

Description	10 yr Sea		10 yr Swell	
Wave (JONSWAP)				
Hs (m)	4.20		3.80	
Tp (sec)	8.3		15.7	
Wave Crest (m)	NA		NA	
Peakedness Parameter	1		6	
Water Level				
Storm Surge (m)	NA		NA	
Tidal Amplitude (m)	NA		NA	
Wind (NPD)				
V (1hr@10 m) - m/s	15.70		14.60	
Direction from Wave (deg)	0		0	
Current	Depth (m)	Vel (m/s)	Depth (m)	Vel (m/s)
	0.00	0.48	0.00	0.48
	-50.00	0.47	-50.00	0.47
	-100.00	0.33	-100.00	0.33
	-150.00	0.33	-150.00	0.33
	-350.00	0.20	-350.00	0.20
	-800.00	0.18	-800.00	0.18
	-1000.00	0.15	-1000.00	0.15
Direction from Wave (deg)	0.00		0.00	

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3.3 Design Criteria

The hull and mooring system for the OTEC MCF is designed to meet the following certification criteria:

- ABS Rules for Building and Classing Mobile Offshore Drilling Units (2001)
- API RP2 FPS - Recommended Practice for Planning, Designing, and Constructing Floating Production Systems (First Edition, March 2001)
- API RP2 SK – Recommended Practice for Design and Analysis of Station Keeping Systems for Floating Structures (Third Edition, October 2005)
- ABS Guidance Notes on the Application of Synthetic Ropes for Offshore Mooring (March 1999)
- API RP2SM – Recommended Practice for Design, Manufacture, Installation, and Maintenance of Synthetic Fiber Ropes for Offshore Mooring (First Edition, March 2001)

Mooring design requirements were assumed to be the following:

- Design life 25 years (fatigue NOT an issue for polyester segment)
- Corrosion allowance 0.4mm/yr x 25 yrs = 10mm
- No touchdown of polyester on seabed
- Offset limitation: limited by power cable design

Mooring line safety factors for dynamic analysis are tabulated in Table 3-5, while polyester stiffness characteristics were listed in Table 3-6. Therein, the MBL stands for the Mean Breaking Load and while the BS stands for Breaking Strength.

Table 3-5 Mooring Line Safety Factors

Mooring Condition	Intact	Damaged
Steel Components (API)	60% BS	80% BS
Synthetic Components (ABS)	55% MBL	70% MBL

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Table 3-6 Polyester Stiffness Characteristics

Type of Analysis	Loop Current Stiffness	Storm Stiffness
Offset	EA = 12.0xMBL	EA = 12.0xMBL
Tension	EA = 17.0xMBL	EA = 24.0xMBL

3.4 Load Cases for Global Performance Analysis

Table 3-7 shows load cases for global performance analysis. Fourteen load cases were identified which can be grouped into operating, extreme and survival cases. Motions and mooring tensions of OTEC MCF are investigated for each configuration.

During pipe manufacturing and pilot test, only four mooring lines are installed, while during production 4 additional mooring lines are added. 100 year cyclone is assumed to be applied during production only. The maximum metocean criterion during pilot test is 25 year cyclone, while during pipe fabrication is 10 year events.

During fabrication, 5MW equipment and pipe fabrication facility are on board and no remoras are installed. During pilot test, 5MW equipment is on board, one remora is installed, and pipe fabrication facility is removed. During production, 10MW equipment is on board, two remoras are installed, and pipe fabrication facility is removed.

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Table 3-7 Load Cases for Global Performance Analysis

Case No	Phase	Environment	Number of Mooring Lines	Remora	Polyester Stiffness	Type of Analysis	Wave Direction (deg towards)	Tide	Mooring Broken	Category
1	Fabrication	10 yr Swell	4	None	Current Stiffness	Offset	0 45 and 225	No	No	Fab Standby
2	Fabrication	10 yr Swell	4	None	Storm Stiffness	Tension	0 45 and 225	No	No	Fab Standby
3	Fabrication	10 yr Sea	4	None	Current Stiffness	Offset	0 45 and 225	No	No	Fab Standby
4	Fabrication	10 Yr Sea	4	None	Storm Stiffness	Tension	0 45 and 225	No	No	Fab Standby
5	Pilot	25 yr Cyclone	4	1 Installed	Current Stiffness	Offset	0 45 and 225	No	No	Extreme
6	Pilot	25 yr Cyclone	4	1 Installed	Storm Stiffness	Tension	0 45 and 225	No	No	Extreme
7	Pilot	25 yr Cyclone	4	1 Installed	Current Stiffness	Offset	0 45 and 225	No	Yes	Survival
8	Pilot	25 yr Cyclone	4	1 Installed	Storm Stiffness	Tension	0 45 and 225	No	Yes	Survival
9	Production	10-yr Swell	8	2 Installed	Current Stiffness	Offset	0 45 and 225	No	No	Operating
10	Production	10-yr Swell	8	2 Installed	Storm Stiffness	Tension	0 45 and 225	No	No	Operating
11	Production	100 yr Cyclone	8	2 Installed	Current Stiffness	Offset	0 45 and 225	No	No	Extreme
12	Production	100 yr Cyclone	8	2 Installed	Storm Stiffness	Tension	0 45 and 225	No	No	Extreme
13	Production	100 yr Cyclone	8	2 Installed	Current Stiffness	Offset	0 45 and 225	No	Yes	Survival
14	Production	100 yr Cyclone	8	2 Installed	Storm Stiffness	Tension	0 45 and 225	No	Yes	Survival

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4 MCF HULL, MOORING, COLD WATER PIPE, AND REMORAS

4.1 Hull Design Principle

The primary requirements for hull sizing are:

- Hydrostatic equilibrium, i.e., buoyancy of MCF hull must equal the total weight plus the total vertical loads.
- The pitch/roll restoring force of the MCF must be sufficient to meet the pitch/roll requirements for the design sea conditions.
- The heave responses must not exceed design limits in design sea states.
- Sufficient variable ballast capacity must be provided for load and weight eccentricities (built-in, operational, and accidental events) and other future loads.
- There must be sufficient air gap between the lowest point of production deck and wave crests.

Constraints imposed by design requirements should be taken care of from the beginning. For the MCF design the following constraints were made clear:

- Distance between columns

  The distance between columns is normally dictated by the size of topside and installation method. In the present design, 50 m of column center to center distance was used.
- MCF draft

  A deeper draft which is translated into long column is usually desired to reduce the heave motions. However, the hull fabrication may be expensive considering the capacity of the lifting equipment. Based on the above reasons the 23 m draft was decided for offshore Hawaii design.

Other important design factors:

- Variable ballast

  A MCF hull is designed for the maximum load condition. However, the load on a MCF will not always be at its maximum. The topside load varies depending on the operating conditions, which will cause the draft of the MCF to change if nothing is done. In case of topsides load change, the MCF can maintain constant draft by changing variable ballast in the variable ballast tanks to compensate for the change in the topsides and other loads.

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- GM value

  GM value is the distance between the center of gravity and metacentric height. This value must be sufficient to keep mean heel angle within the allowable range when there are overturning moments and also to avoid the pitch/roll natural periods of being close to the wave energy. GM of 4.5 m to 6.0 m was selected as the target value of MCF hull design.

4.2 Topside Effective Wind Area

The topside effective wind area and wind force center of pressure are based on the best estimate number as dictated by the topside dimension provided by Houston Offshore Engineering (Ref. 4 Drawing No H09102-H-0013 and H09102-H-0014). Figures 4-1 and 4-2 show the wind effective area during pipe fabrication and production, respectively. For pilot test, the area is assumed to be somewhat between the pipe fabrication and production.

Table 4-1 shows detail number of wind effective area and corresponding center of pressure. For analysis purposes and considering the phase of the project, omni directional numbers are used.

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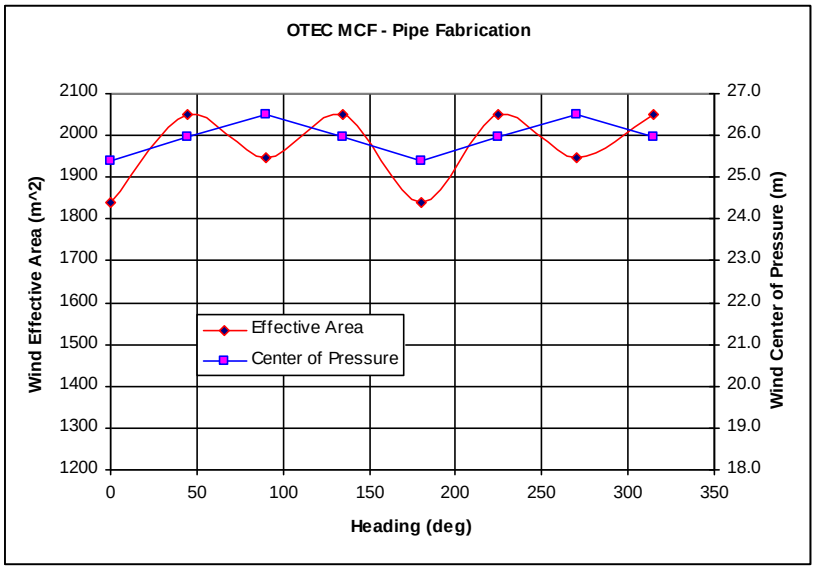


Figure 4-1 Wind Effective Area Estimation during Pipe Fabrication

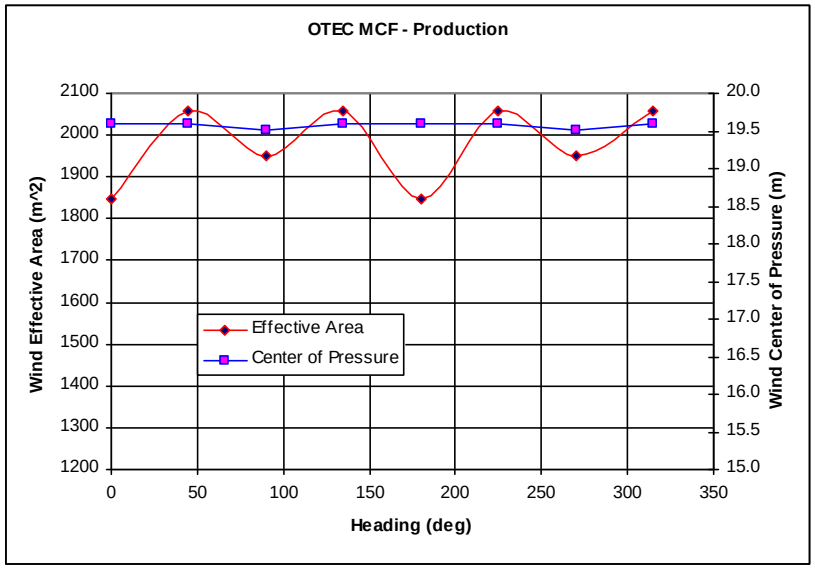


Figure 4-2 Wind Effective Area Estimation during Production

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Table 4-1 Wind Effective Area and Center of Pressure

Direction	Topside - Pipe Fabrication		Topside - Production	
	Area	Cp from MWL	Area	Cp from MWL
(deg)	(m2)	(m)	(m2)	(m)
0	1840	25.4	1846	19.6
45	2052	26.0	2058	19.6
90	1946	26.5	1952	19.5
135	2052	26.0	2058	19.6
180	1840	25.4	1846	19.6
225	2052	26.0	2058	19.6
270	1946	26.5	1952	19.5
315	2052	26.0	2058	19.6
Omni	2052	26.5	2058	19.6

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4.3 Hull and Remora Dimension

The hull and remora used for the global performance analysis is summarized in Tables 4-2 and 4-3 while hull inboard profile and plan view are shown in Figures 4-3 and 4-4.

Table 4-2 MCF Hull Dimension

MCF Dimension			
Principal Inputs		**Value**	**Units**
	Water Depth	1100.0	m
	Dram	23.0	m
	Freeboard	13.0	m
	Depth from Water Line to Strakes	0.0	m
Column			
	Number of Columns	4	
	Number of Cell per Columns	4	
	Cell Diameter	5.5	m
	Cell Spacing	1.0	m
	Cell Center to Center Spacing	6.5	m
	Cell to Pontoon Edge	1.8	m
	Lower Column Width	15.6	m
	Lower Column Length	15.6	m
	Lower Column Height	5.0	m
	Column Dram	23.0	m
	Column Corner Radius	0.0	m
	Column Depth	36.0	m
	Column Center to Center Spacing Length	52.0	m
	Column Center to Center Spacing Width	52.0	m
	Column Inside Spacing Length	40.0	m
	Column Inside Spacing Width	40.0	m
Pontoon			
	Number of Pontoons	1.2	m
	Pontoon Width (Outer)	9.6	m
	Pontoon Corner Radius	0.0	m
	Pontoon Length (Outer)	36.4	m
	Pontoon Height	5.0	m
	Tunnel Length	NA	
	Tunnel Height	NA	
	Pontoon End Length (Outer)	3.0	m
	Pontoon End Width	6.0	m

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Table 4-3 Remora Dimension

Remora Dimension			
		Value	Units
	Maximum Number of Remora	2	
	Remora Diameter	15.0	m
	Remora Freeboard	20.0	m
	Remora Depth	110.0	m
	Remora Below Hull Keel	67.0	m
	Remora Draft	90.0	m

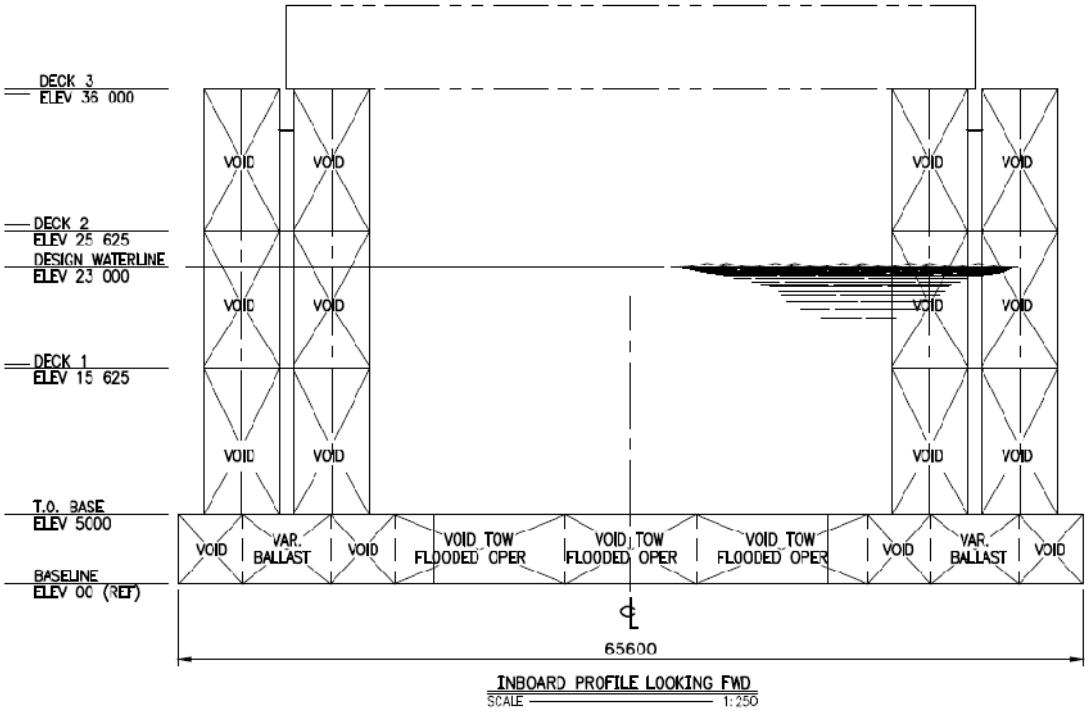


Figure 4-3 MCF Inboard Profile

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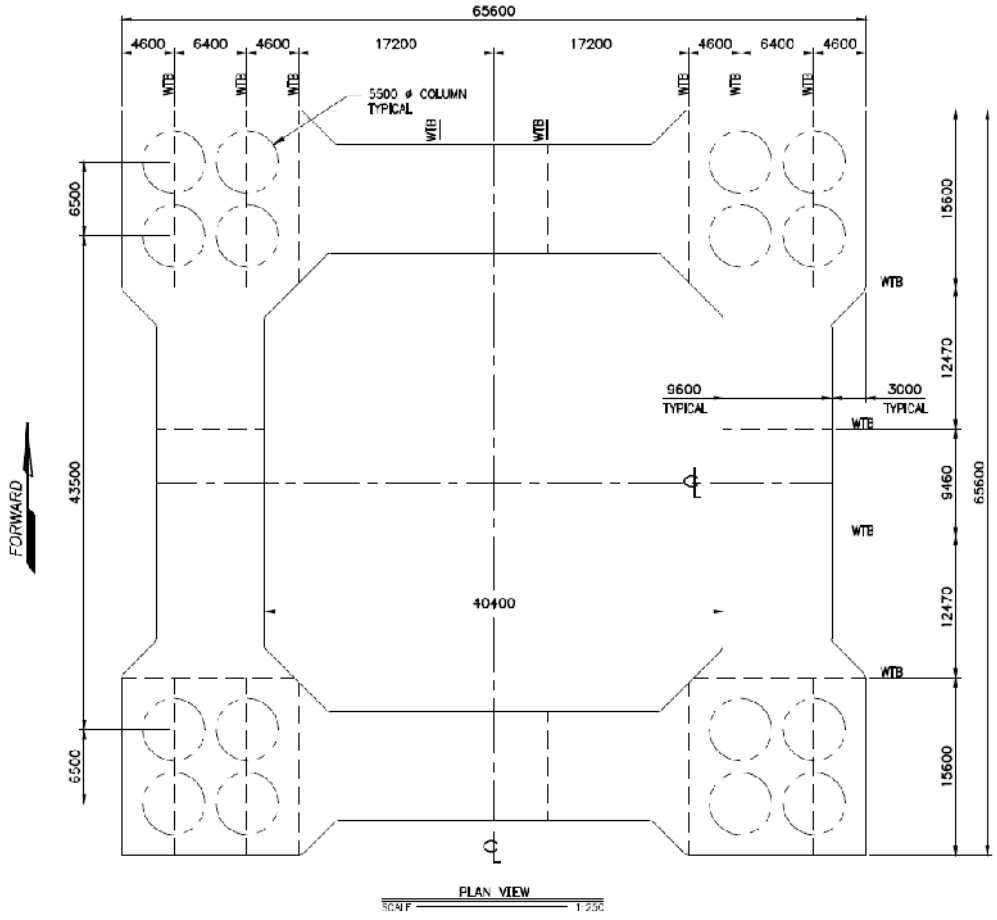


Figure 4-4 MCF Plan View

4.4 Hull and Remora Weight

Hull and Remora weight in this study is presented in Table 4-4 and 4-5, respectively. Weigh and hydrostatic properties in Table 4-4 represent the MCF platform during pipe fabrication. Mooring vertical loads, however, need to be adjusted (4 mooring lines instead of 8).

During pilot test and production, the properties are shown in Table 4-6 and 4-7. The hydrostatic properties are derived based on 23 m operating draft and the mooring vertical load is from 1,000 m nominal water depth.

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Table 4-4 MCF Weight and Hydrostatic Properties – Pipe Fabrication

MCF Weight			
Buoyancy			
		Buoyancy (kN)	KB (m)
	Column	117,717.7	9.2
	Pontoon	70,017.7	2.5
	Diffuser	2,555.8	5.0
	Top and Bottom CWP Guide and Truss	1,264.6	3.2
	Total Displacement	191,555.8	6.7
Connectors			
		Load (kN)	KG (m)
	Cold Water Pipe	3,452.5	1.5
	Mooring Vertical Force (8 Lines)	7,913.0	3.0
	SCR Vertical Force	0.0	4.3
	Entrapped Water in Diffuser	2,555.8	5.0
Weights			
		W (kN)	KG (m)
	Pontoon Steel	11,060.4	2.5
	Column Steel	27,250.7	15.9
	Diffuser Steel	199.7	5.0
	Top and Bottom CWP Guide and Truss	5,081.0	5.5
	Total Hull Steel	43,591.3	11.2
	Outfitting (wet)	19,963.1	18.4
	Total Lightship Weight	63,554.4	13.5
	Fixed Ballast	0.0	0.9
	Entrained Water+Variable Ballast	73,661.5	2.4
	Liquids & Consummables	0.0	0.0
	Topside Weight	41,408.7	42.3
	Total Weight	177,634.9	15.4
	Total Vertical Load including Connector Loads	192,545.9	14.7
Radii of Gyration			
	Roll Radius of Gyration (m)	26.6	
	Pitch Radius of Gyration (m)	26.6	
	Yaw Radius of Gyration (m)	28.6	
Hydrostatics			
	Total Underwater Volume (cu.m)	19,152.9	
	Waterplane Area (sq. m)	380.1	
	Area Moment of Inertia in Roll/Pitch (m4)	242,316.8	
	BM (m)	12.7	

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Table 4-5 Remora A and B Weight

Remora Weight			
Buoyancy			
		Weight (kN)	VCG (m)
	Design Displacement	104,296.7	-1.8
Weights			
	Steel Weight + Outfitting	56,170.7	-8.5
	Vertical Force	0.0	-67.0
	Additional Weight (Amonia etc.)	7,282.7	-13.9
	Entrained Water	40,843.3	-23.8
	Total Weight	104,296.7	-14.8

Table 4-6 Combine Hull and Remora B Weight – Pilot Test

Hull and Remora B			
Weight and Buoyancy			
		Weight (kN)	VCG (m)
	Total Displacement	244,694.3	4.9
	Total Weight with Remora without Connector Loads	230,772.9	8.7
	Total Weight with Remora with Connector Loads	244,694.3	8.4
Radii of Gyration			
	Roll Radius of Gyration (m)	31.2	
	Pitch Radius of Gyration (m)	36.1	
	Yaw Radius of Gyration (m)	31.1	
Hydrostatics			
	Waterplane Area (sq. m)	556.8	
	Area Moment of Inertia in Roll (m4)	244,801.8	
	Area Moment of Inertia in Pitch (m4)	571,547.1	
	BMx (m)	10.1	
	BMy (m)	23.5	
	GMx without Connector Loads (m)	6.2	
	GMx with Connector Loads (m)	6.6	
	GMy without Connector Loads (m)	19.7	
	GMy with Connector Loads (m)	20.0	

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Table 4-7 Combine Hull and Remora A+B Weight – Production

Hull and Remora A + B			
Weight and Buoyancy			
		Weight (kN)	VCG (m)
	Total Displacement	296,842.6	3.7
	Total Weight with Remora without Connector Loads	282,921.3	4.4
	Total Weight with Remora with Connector Loads	296,842.6	4.3
Radii of Gyration			
	Roll Radius of Gyration (m)	33.3	
	Pitch Radius of Gyration (m)	43.6	
	Yaw Radius of Gyration (m)	36.3	
Hydrostatics			
	Waterplane Area (sq. m)	733.6	
	Area Moment of Inertia in Roll (m4)	247,286.9	
	Area Moment of Inertia in Pitch (m4)	900,777.4	
	BMx (m)	8.4	
	BMy (m)	30.5	
	GMx without Connector Loads (m)	7.7	
	GMx with Connector Loads (m)	7.8	
	GMy without Connector Loads (m)	29.8	
	GMy with Connector Loads (m)	29.9	

4.5 Mooring System

The OTEC MCF has 8 fairleads with two located at each corner of the pontoon. The mooring lines are arranged in four groups with two lines in each group. The lines are space five degrees apart and arrange in a symmetric pattern about a 45 degree line projected from each corner of the deck The fairleads are assumed to be located at 2.5 m above keel. The side view of mooring line no. 1 is shown in Figures 4-5 and the plan view for all mooring lines is shown in Figure 4-6.

As shown in Figures 4-5 for 970 m water depth, 14 m long of polyester test section (for in-service evaluation) is inserted on each line as recommended by API. Considering to the manufacturing, transporting and installation, the polyester ropes for the wire section is divided into 2 segments and each segment is connected through connectors. There are three connectors for each line and the weight of each connector is assumed to be 35 kN.

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As shown in Figure 4-6, water depth at each anchor location is varied. The solution proposed in this study was to keep the scope ratio (line length divided by water depth) constants. After performing mooring analysis, 1.7 of scope ratio is selected to be an optimized solution considering mooring size, anchor type and hull offset during the storm. Since the scope ratio is kept constant, the length of each mooring is varied.

For all configurations (pipe manufacturing, pilot test, and production), the chain and polyester diameters are 105 mm and 228.5 mm, respectively. Mooring line properties and corresponding pretensions are presented in Tables 4-8and 4-9. Table 4-10 shows the fairlead and anchor locations.

As described in Table 3-7, only 4 mooring lines are installed during pipe manufacturing and pilot test. Four additional lines are added later during production. The vertical loads due to different number of mooring lines will be adjusted by water ballast to keep the hull draft in targeted value.

Due to the non-linear behavior of the polyester rope, its stiffness is a function of tension, dynamic load range and period of loading. The stiffness under static loading is significantly lower than that under dynamic loading. For this study, the static stiffness was set at 12 times the breaking strength while dynamic stiffness was set at 24 times the breaking strength. For each environmental loading event studied, two set of analysis with two different stiffness values have been performed. This approach allows for the calculation of the maximum offset and maximum line tension in conservative side.

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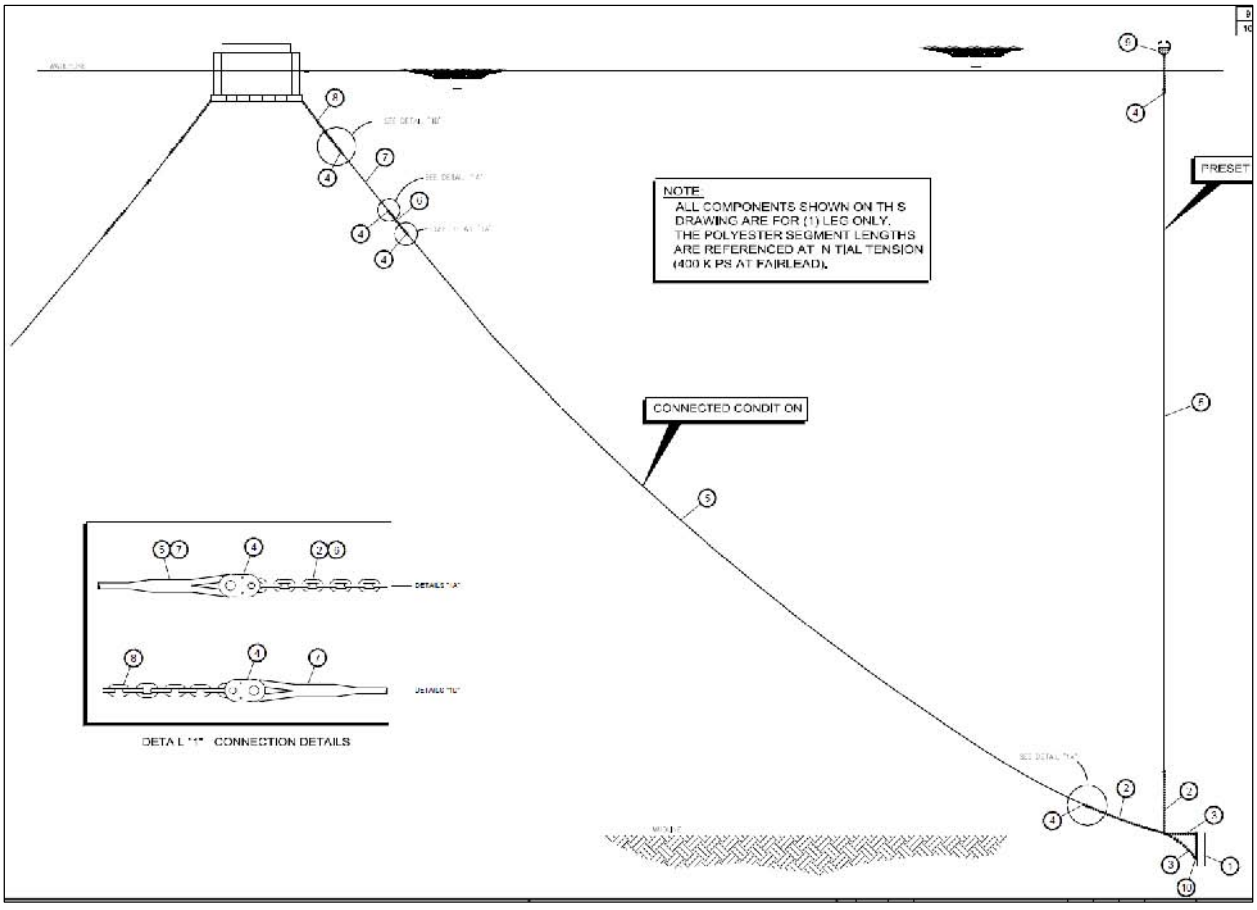


Figure 4-5 Mooring Line Layout (Side View)

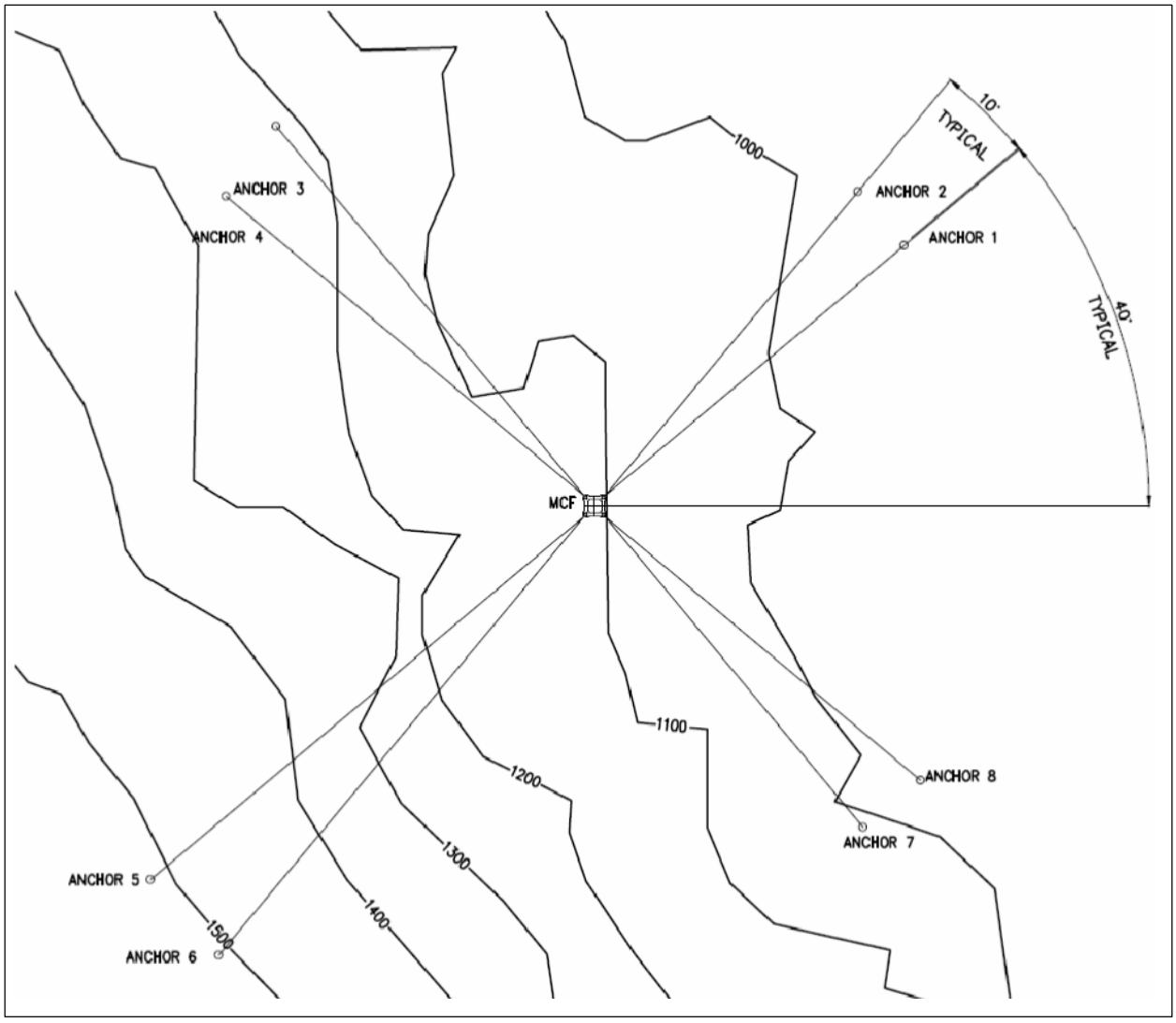


Figure 4-6 Mooring Line Layout (Plan View)

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Table 4-8 Mooring Line Properties

Line Properties	Unit	Platform Chain	Test Section	Connecting Chain	Riser Wire	Ground Chain
Type		R5 Studless	Polyester	R5 Studless	Polyester	R5 Studless
Diameter	mm	104.8	228.5	104.8	228.5	104.8
Length						
Group 1 (Line 1&2)	m	90.0	14.0	15.0	1450	75.0
Group 2 (Line 3&4)	m	90.0	14.0	15.0	1857	75.0
Group 3 (Line 5&6)	m	90.0	14.0	15.0	2365	75.0
Group 4 (Line 7&8)	m	90.0	14.0	15.0	1518	75.0
Dry Weight	kg/m	220.2	29.8	220.2	29.8	220.2
Wet Weight	kg/m	191.5	10.3	191.5	10.3	191.5
MBL Uncorroded	kN	12,459	11,885	12,459	11,885	12,459
MBL Corroded	kN	10,631	NA	NA	NA	NA
MBL Analysis	kN	10,549	NA	NA	NA	NA
EA	kN	857,494	12.-24.xMBL	1,146,899	12.-24.xMBL	1,146,899
Added Mass Coef.		1.00	1.00	1.00	1.00	1.00
Drag Coef. (cd)		2.45	1.20	2.45	1.20	2.45

Table 4-9 Mooring Line Pretensions

Line Number	Unit	Pretension
1	kN	1410.0
2	kN	1410.0
3	kN	1468.0
4	kN	1468.0
5	kN	1468.0
6	kN	1468.0
7	kN	1430.0
8	kN	1430.0

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Table 4-10 Fairlead and Anchor Locations

Line Number	Azimuth form Platform North	X-fairlead	Y-fairlead	Z-fairlead	Mooring departure Angle from PE	X-anchor	Y-anchor	Z-anchor
	(deg)	(m)	(m)	(m)	(deg)	(m)	(m)	(m)
1	40.0	36.2	30.4	-20.5	40.0	944.9	792.9	-970.0
2	50.0	30.4	36.2	-20.5	50.0	802.8	956.7	-980.0
3	130.0	-30.4	36.2	-20.5	130.0	-970.5	1156.6	-1210.0
4	140.0	-36.2	30.4	-20.5	140.0	-1124.3	943.4	-1270.0
5	220.0	-36.2	-30.4	-20.5	220.0	-1353.8	-1136.0	-1510.0
6	230.0	-30.4	-36.2	-20.5	230.0	-1146.5	-1366.3	-1510.0
7	310.0	30.4	-36.2	-20.5	310.0	819.3	-976.4	-1010.0
8	320.0	36.2	-30.4	-20.5	320.0	994.7	-834.7	-990.0

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5 NUMERICAL MODELLING

5.1 Time Domain Analysis with HARP/CHARM3D

Time domain simulation was chosen for the global motion analysis for the MCF. The non-linear load/response effects include:

- Mooring stiffness/load
- First-order wave force at instantaneous location on instantaneous wetted surface
- Viscous drift forces
- Relative velocity between the fluid and the body
- Dynamic wind load
- Mean drift force and low frequency force
- Hydrodynamic loads on cold water pipe
- Hydrodynamic loads on remoras

The time domain analysis is performed using the HARP/CHARM3D program written by Offshore Technology Research Center (OTRC), Texas A&M University [Ref.1]. The coordinate system and heading definition of CHARM3D is shown in Figures 5-1 and 5-2, respectively. The origin is located at the center of the mean water level. The X-axis is along the platform east and the Y-axis point to the platform north and the Z-axis coincides with the platform central line and points up. The environmental headings are defined in the azimuth angles which are the angles measuring from the X-axis. The heading angle is positive counter-clockwise from the X-axis.

5.2 Prediction of Extreme Values

The maximum values of the response are estimated from 1-hr simulations. Typical response statistics (mean, minimum and maximum simulation values, standard deviation, zero crossing period, etc.) are obtained through post-processing of the time domain analysis results. The extreme statistic values are derived from the three-parameter Weibull distribution. The MCF global performance was analyzed with a time step of 0.05 second.

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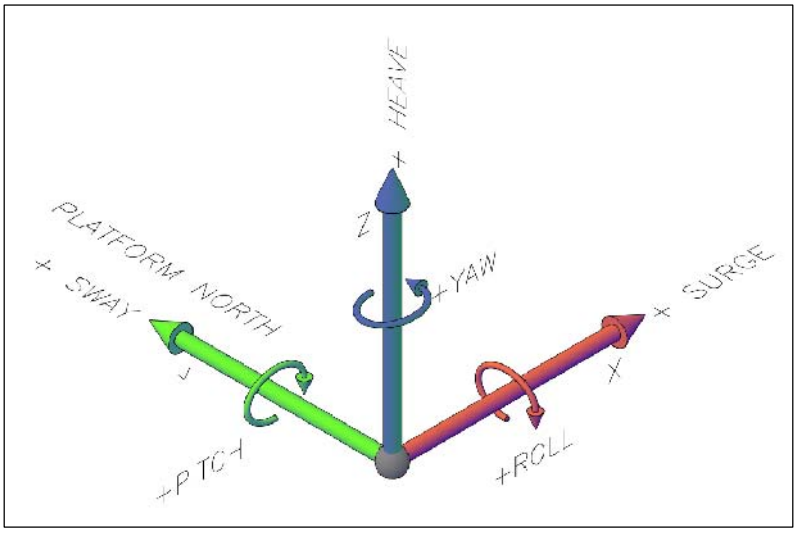


Figure 5-1 Coordinate System Definition

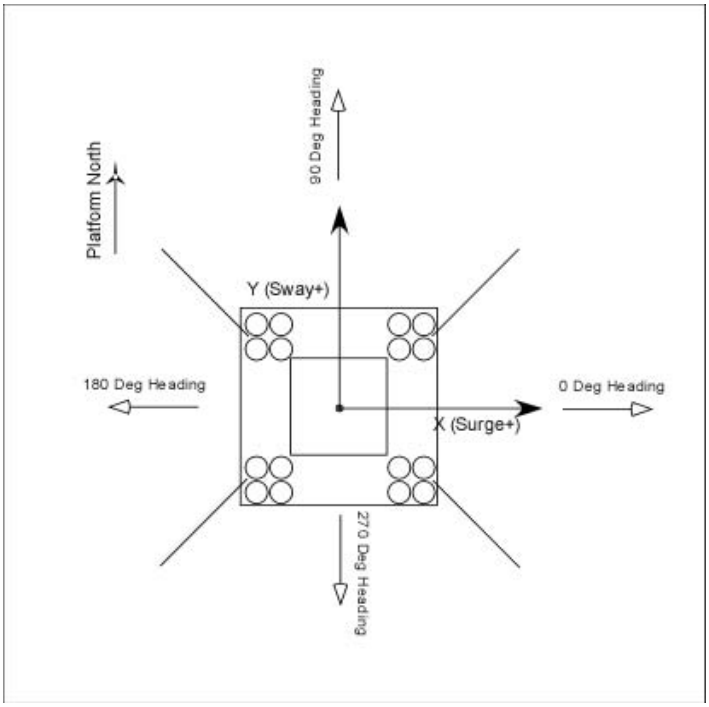


Figure 5-2 Heading Definition

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5.3 Fully Coupled Model

Figures 5-3 and 5-4 show the fully coupled model of the OTEC MCF during production using CHARM3D. As shown in Figure 5-4, CWP was connected to one end to the keel truss of MCF hull through fixed connection and the other end hanging above the sea floor. CWP connection to MCF keel truss is assumed to be fixed until further definition of diffuser properties and type of hang-off connection.

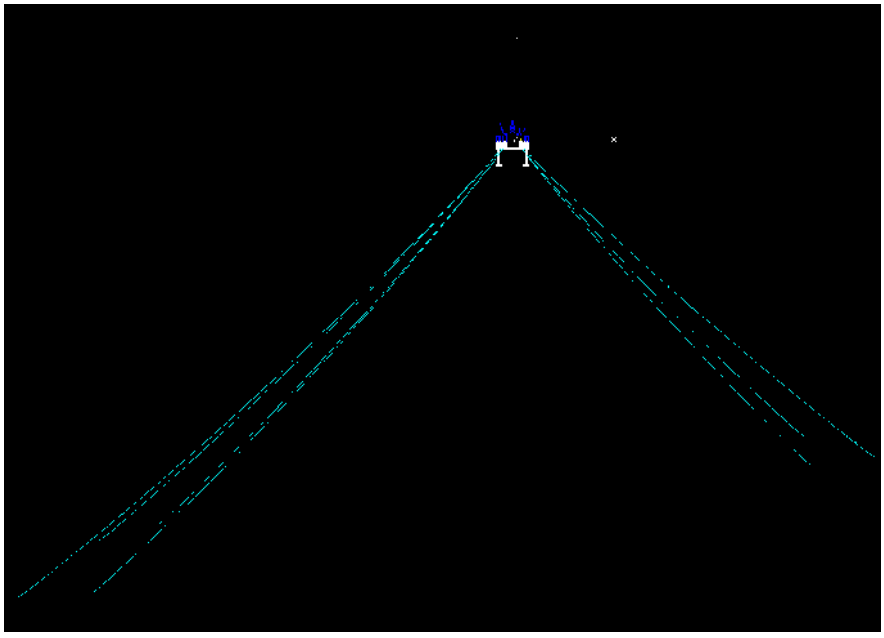


Figure 5-3 Fully-coupled Analysis Model (Global View)

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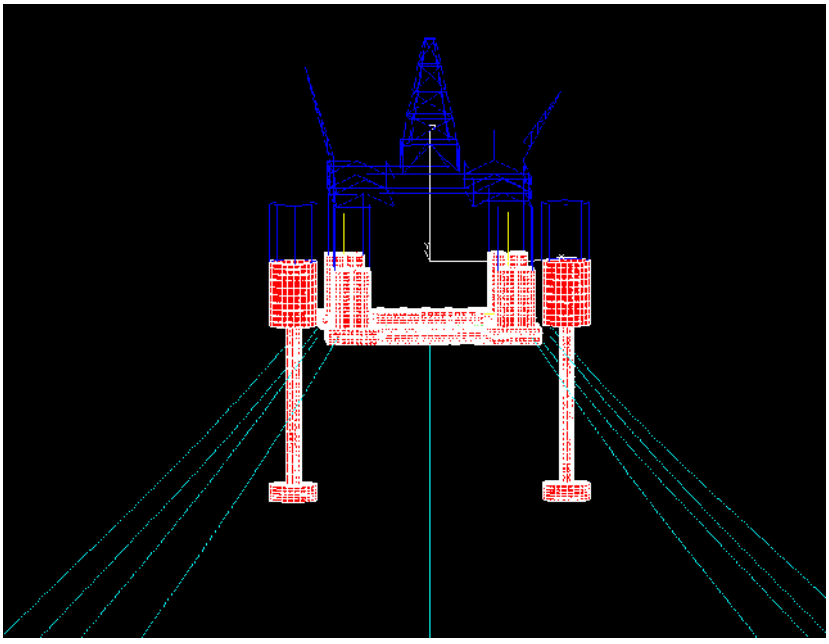


Figure 5-4 Fully-coupled Analysis Model (Detailed View)

5.4 Hydrodynamic Coefficients

The hydrodynamic coefficients used for the analysis all environments are summarized in Table 5-1. Drag coefficient values are based on the previous MCF designs and need to be confirmed during detailed design.

The added mass and hydrodynamic damping, first-order wave-frequency forces, and second order mean are calculated from the first-order diffraction/radiation program WAMIT [Ref. 5]. The radiation and diffraction velocity potentials on the body wetted surface are determined from solution of an integral equation obtained using Green's theorem with the free-surface source-potential as the Green function.

All the hydrodynamic coefficients from WAMIT are calculated in the frequency domain, and then the corresponding forces are converted to the time domain in CHARM3D. The frequency-dependent radiation damping is included in the form of convolution integral in the time domain simulation. Slowly-varying wave-forces are included in the analysis using Newman's approximation [Ref. 6]. WAMIT panel model of OTEC MCF for different configuration is shown in Figures 5-5 to 5-7.

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Table 5-1 Hydrodynamic Coefficients

Member	Drag Coefficients	Added Mass Coefficients
	Cd	
Column		
Lateral - horizontal (z)	0.80	WAMIT
Lateral - horizontal (y)	0.80	WAMIT
Axial - vertical (x1)	0.00	WAMIT
Axial - vertical (x2)	0.00	WAMIT
Pontoon		
Lateral - horizontal (y)	0.53	WAMIT
Lateral - vertical (z)	7.28	WAMIT
Axial - horizontal (x1)	0.00	WAMIT
Axial - horizontal (x2)	0.00	WAMIT
Pontoon Corner		
Lateral - horizontal (z)	0.96	WAMIT
Lateral - horizontal (y)	0.96	WAMIT
Axial - vertical (x1)	2.00	WAMIT
Axial - vertical (x2)	2.00	WAMIT
Remora		
Lateral - horizontal (z)	0.60	WAMIT
Lateral - horizontal (y)	0.60	WAMIT
Axial - vertical (x1)	2.00	WAMIT
Axial - vertical (x2)	0.00	WAMIT

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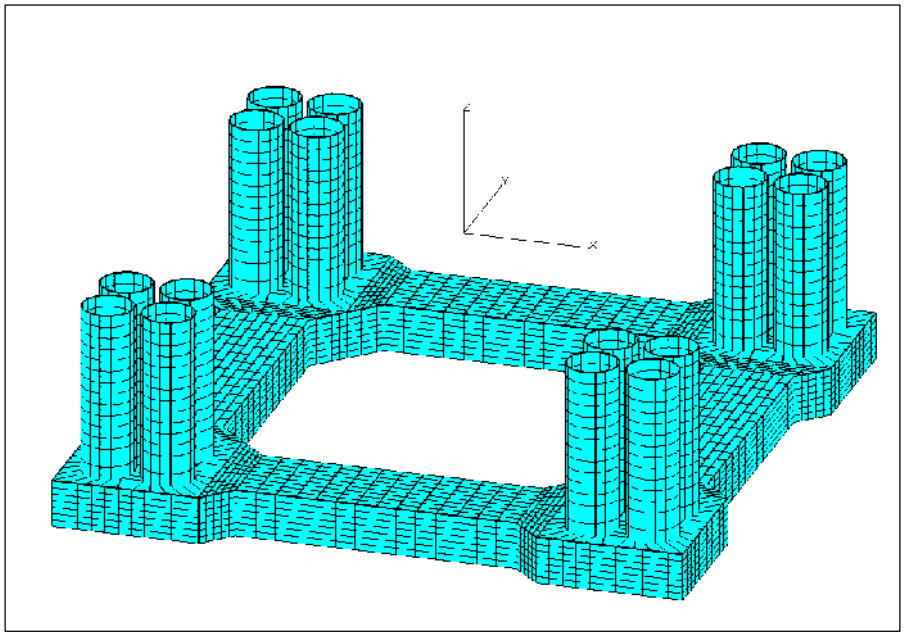


Figure 5-5 WAMIT Panel Model of OTEC MCF during Fabrication

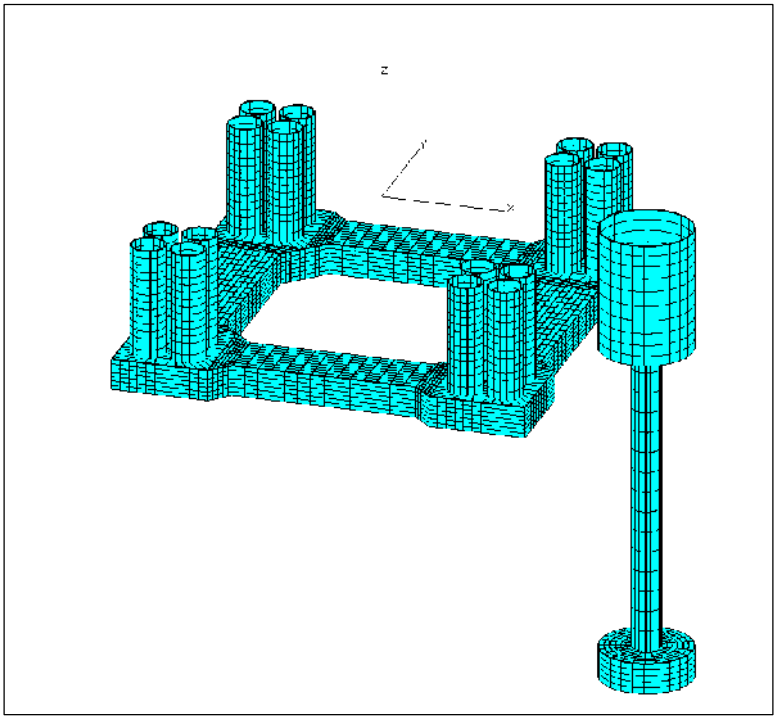


Figure 5-6 WAMIT Panel Model of OTEC MCF during Pilot

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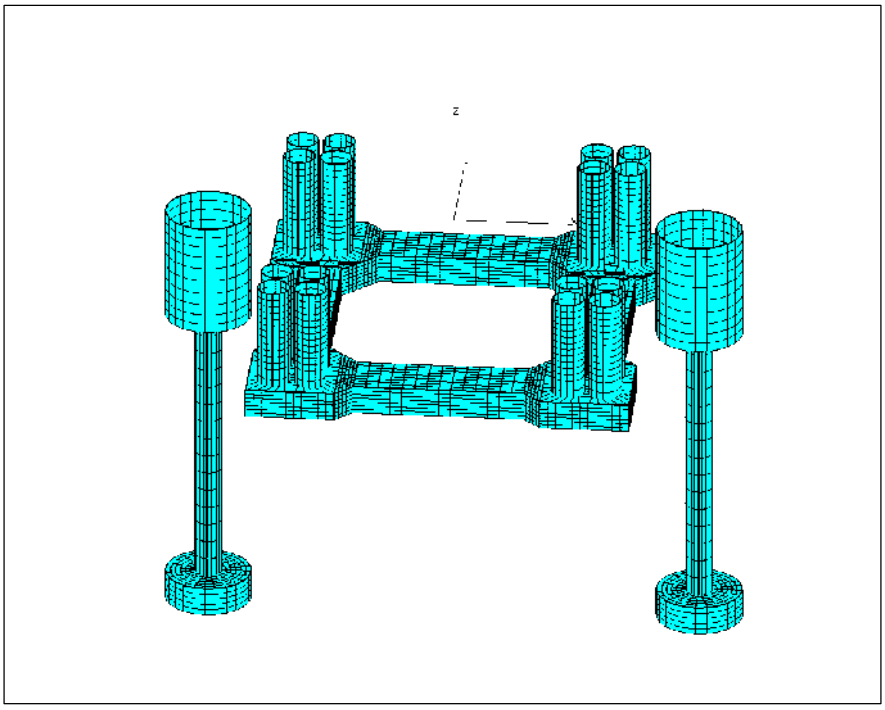


Figure 5-7 WAMIT Panel Model of OTEC MCF during Production

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6 GLOBAL PERFORMANCE RESULTS

6.1 Natural Periods

Free decay tests are conducted to estimate the natural periods (Tn) of the MCF and the result are shown in Table 63-1 for pipe fabrication and production configurations. The free decay tests for both configurations are shown in Figures 6-1.and 6-2.

Table 6-1 MCF Natural Periods

Natural Periods		Pipe Fabrication	Production
Motion	**Unit**	**Hull**	**Hull**
Surge	sec	112.0	115.5
Sway	sec	124.0	115.5
Heave	sec	25.0	20.0
Roll	sec	27.7	26.7
Pitch	sec	27.0	18.8
Yaw	sec	72.7	51.3

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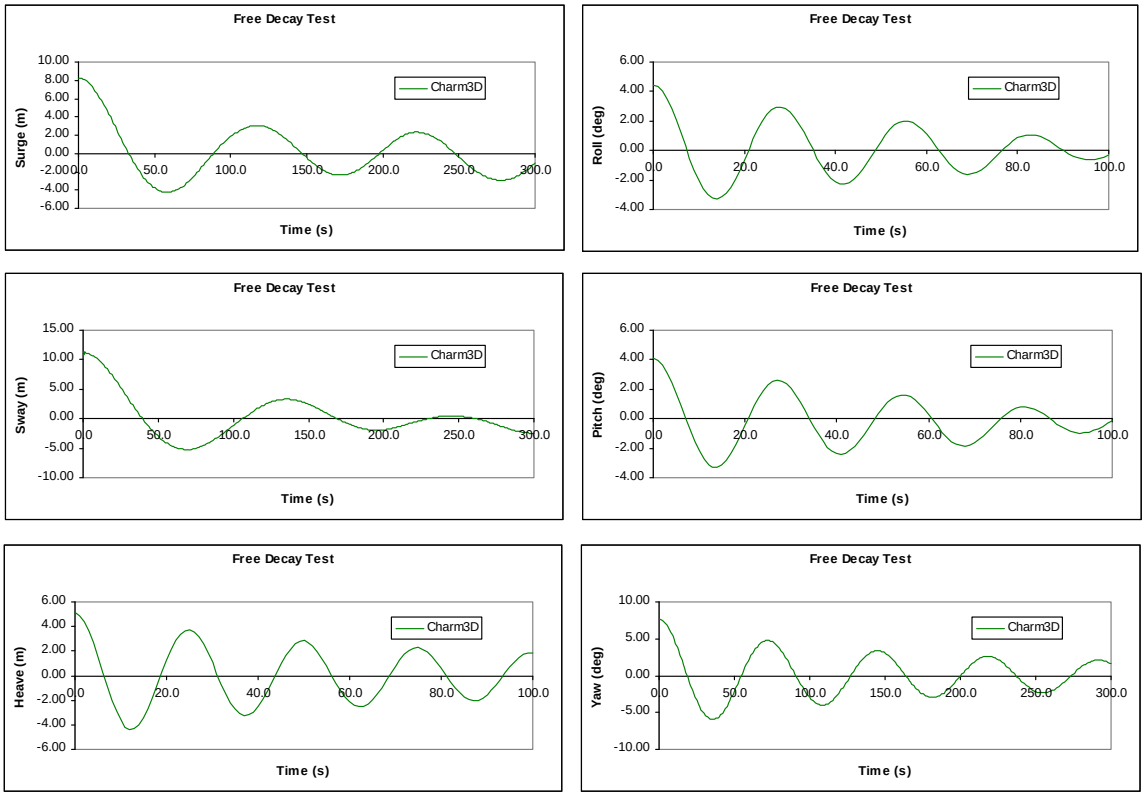


Figure 6-1 Free Decay Test of OTEC MCF during Pipe Fabrication

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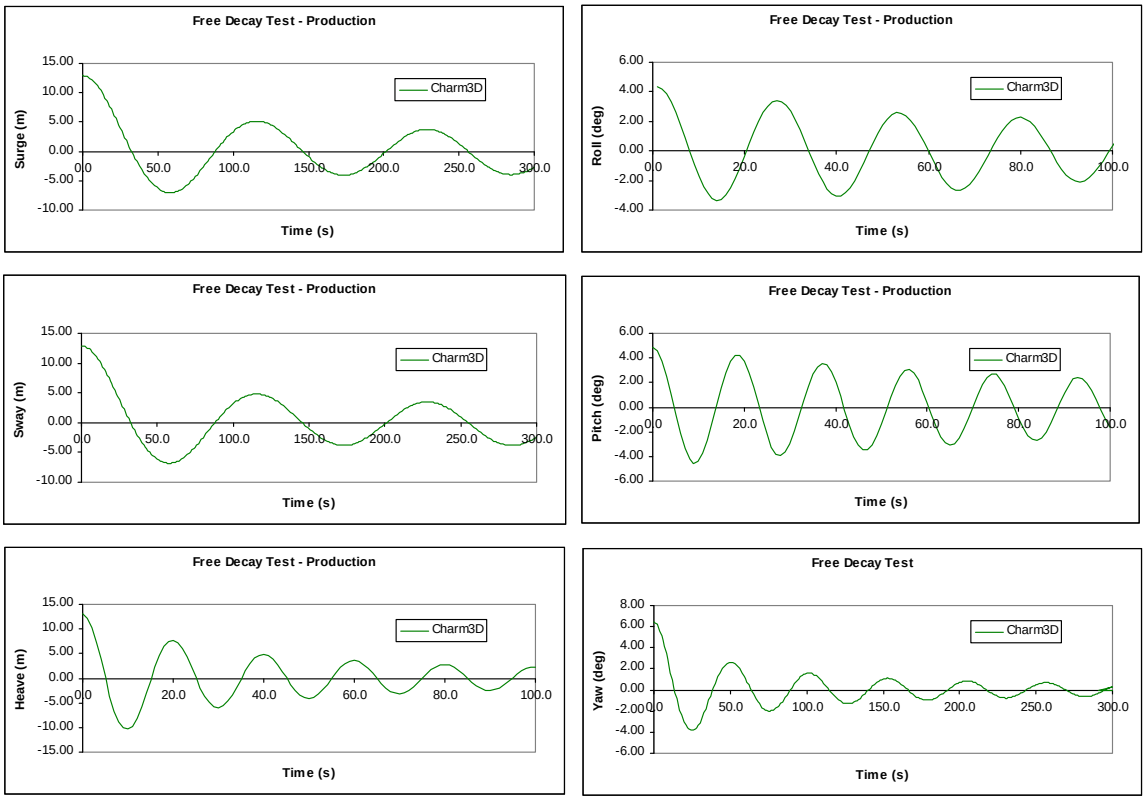


Figure 6-2 Free Decay Test of OTEC MCF during Production

6.2 Response Amplitude Operators (RAOs)

Figures 6-3 through 6-5 show predicted RAO of the OTEC MCF for different configuration, which was derived using WAMIT and included linear damping only.

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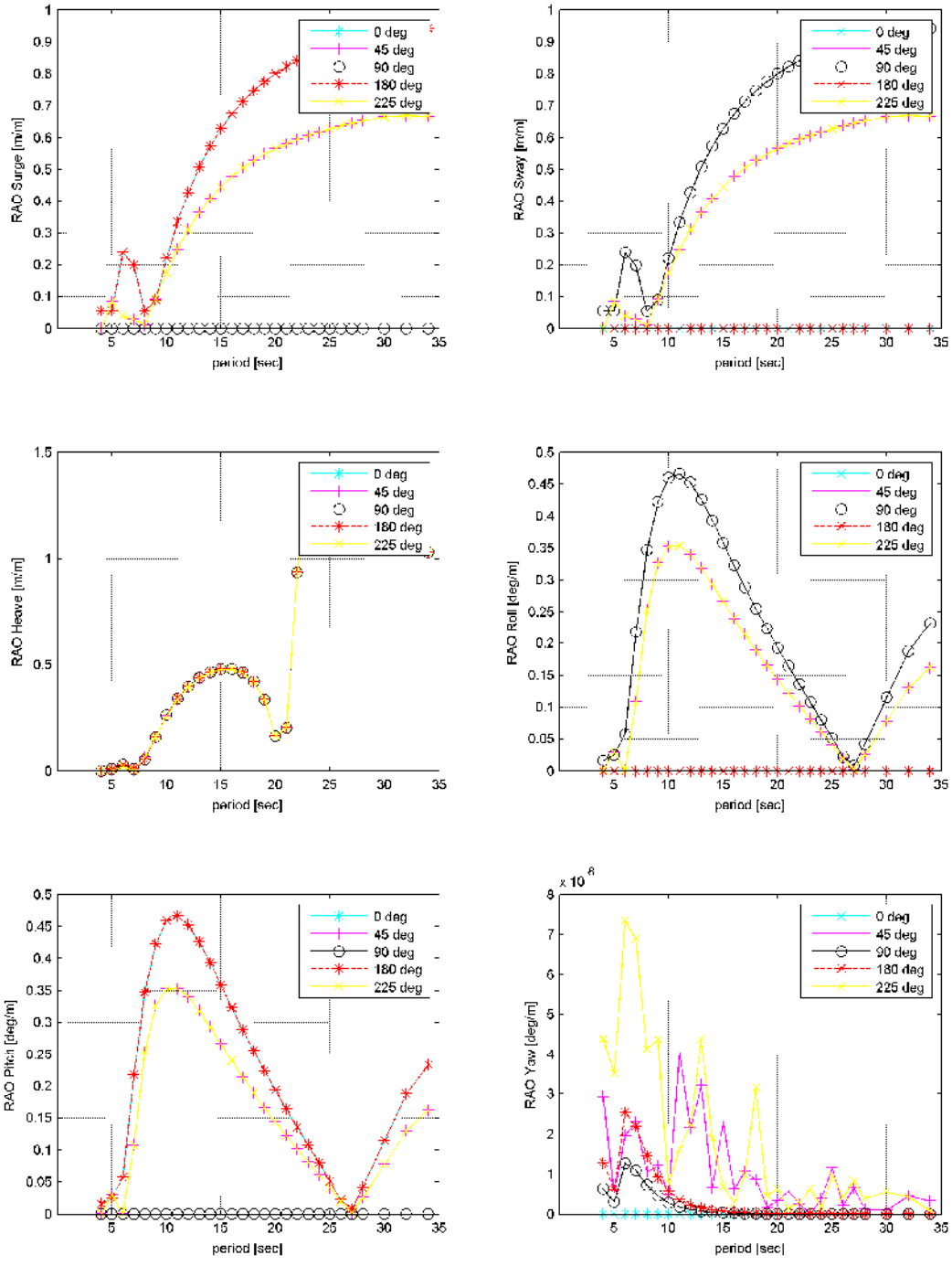


Figure 6-3 MCF RAOs – Pipe Fabrication

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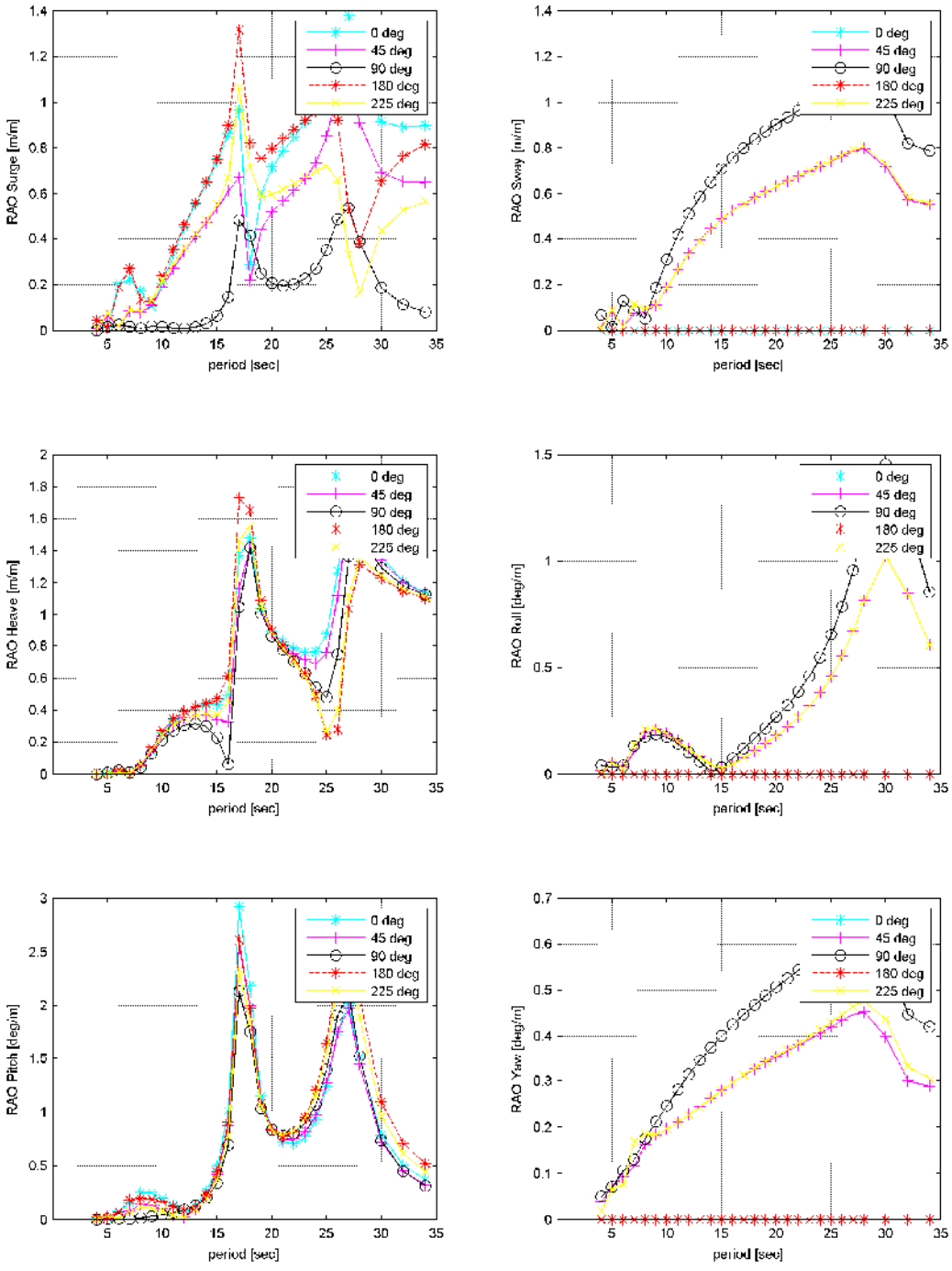


Figure 6-4 MCF RAOs – Pilot Test

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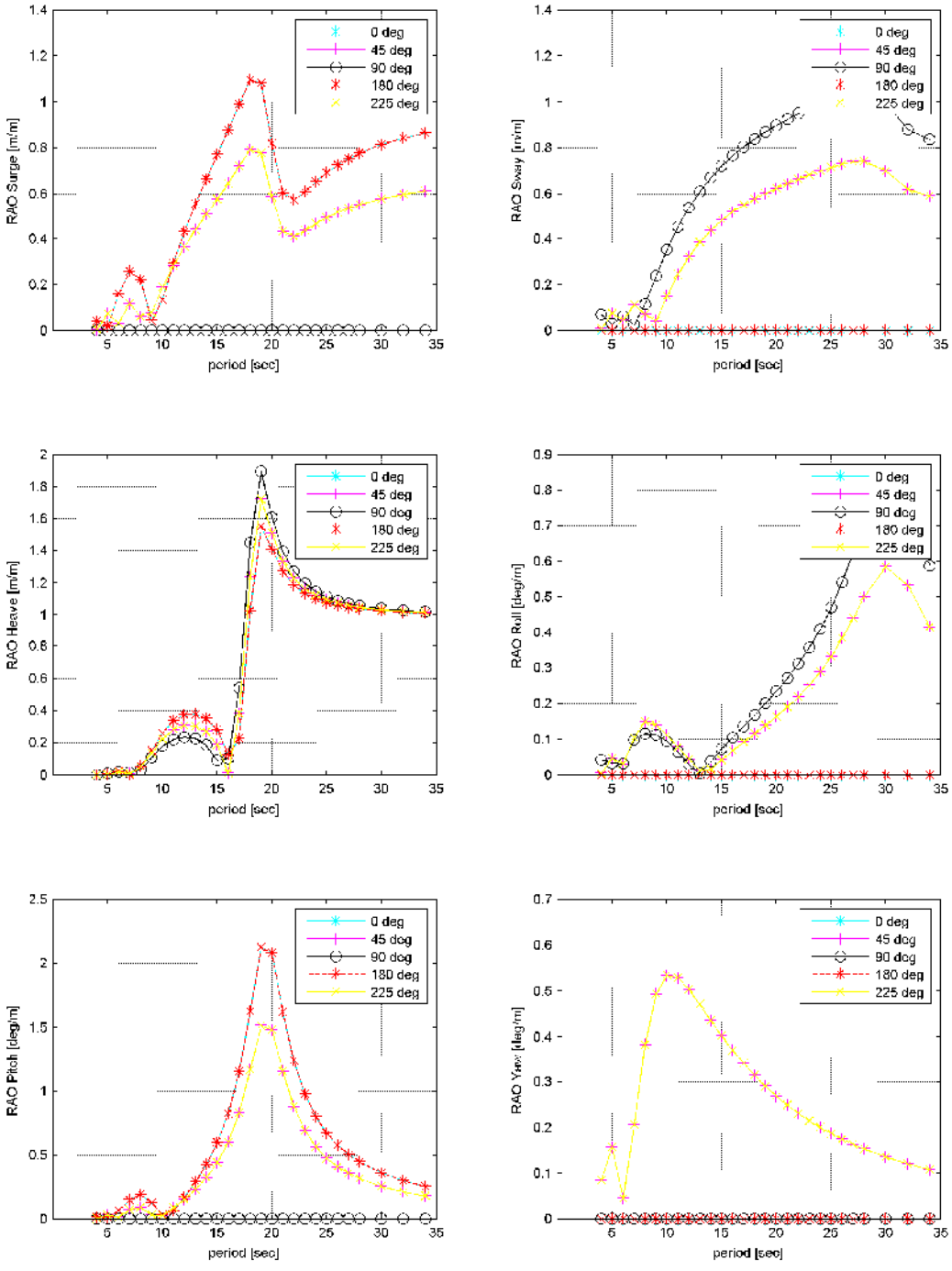


Figure 6-5 MCF RAOs – Production

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6.3 Hull Motion Responses in Time Domain Simulations

Environmental heading screening was performed 3 different headings to determine the critical headings for vessel motions, mooring tension, topside acceleration, and anchor loads. For each heading, fully coupled time domain simulations were carried out with one realization of a 1-hours duration and extreme values as predicted based on Weibull distribution. Longer durations and more realizations can be done during the detailed design phase.

All motion results presented in this report are with respect to the mean water level unless otherwise specified. Offset is defined as vector summation of surge and sway, while heel is defined as vector summation of roll and pitch. Notice that in this section the maximum offset is presented in meter. The maximum mooring tension is shown in terms of usage factor which is defined as the maximum mooring tension divided by line breaking strength (BS) for chain, while for polyester it is defined as maximum tension at polyester segment divided by the mean breaking load (MBL). The acceleration at topside is computed at 25 m above mean water level.

Response in Pipe Manufacturing Configuration

MCF motions and accelerations during 10 year Sea and 10 year Swell events with intact condition are presented in Table 6-2. In these events, the maximum offset is 14.5 m and maximum heel is 2.18 degree. The results show that the MCF response is in typical range of offshore structure. The maximum heave ranges for MCF hull is about 1.86 m.

The maximum lateral acceleration at the topside is 0.09 g.

The maximum mooring tensions in 10 year events for chain and polyester are listed in Table 6-3 and 6-4, respectively. In intact condition the usage factor of chain is 0.23 and the allowable is 0.6. This means there is 161% margin of chain strength.

For the polyester segment, the usage factors in intact condition are 0.19. That usage factors translate into 189% margin.

The maximum horizontal and vertical anchor loads during 10 year events are around 1,890 kN and 1,058 kN, respectively.

Summary statistic of motions, acceleration, mooring tension and anchor loads during pipe manufacturing are shown Appendix A. Detail anchor loads are tabulated in Appendix D.

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Table 6-2 Motion and Acceleration – Pipe Manufacturing

Motions and Accelerations							
Environment	**Mooring Condition**	**Hull Condition**	**Hull Max Offset**	**Hull Min Heave**	**Hull Max Heave**	**Hull Max Heel**	**Lat. Acc @Topside**
			(m)	(m)	(m)	(deg)	(g)
10 Year Sea	Intact	Intact	14.50	-0.44	0.44	2.00	0.09
	Broken Line	Intact					
10 Year Swell	Intact	Intact	10.80	-0.99	0.87	2.18	0.03
	Broken Line	Intact					

Table 6-3 Mooring Line Tension at Chain – Pipe Manufacturing

Tension @ Chain						
Environment	**Mooring Condition**	**Maximum Tension**	**Breaking Strength**	**Usage Factor**	**Allowable Usage**	**Margin**
		(kN)	(kN)			(%)
10 Year Sea	Intact	2426.27	10549.00	0.23	0.60	160.87
	Broken Line					
10 Year Swell	Intact	2215.29	10549.00	0.21	0.60	185.71
	Broken Line					

Table 6-4 Mooring Line Tension at Polyester – Pipe Manufacturing

Tension @ Polyester						
Environment	**Mooring Condition**	**Maximum Tension**	**Breaking Strength**	**Usage Factor**	**Allowable Usage**	**Margin**
		(kN)	(kN)			(%)
10 Year Sea	Intact	2258.15	11885.00	0.19	0.55	189.47
	Broken Line					
10 Year Swell	Intact	2020.45	11885.00	0.17	0.55	223.53
	Broken Line					

Table 6-5 Anchor Forces – Pipe Manufacturing

Anchor Forces			
Environment	**Mooring Condition**	**Horizontal Force**	**Vertical Force**
		(kN)	(kN)
10 Year Sea	Intact	1890.00	1058.00
	Broken Line		
10 Year Swell	Intact	1711.00	944.00
	Broken Line		

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Response in Pilot Test Configuration

MCF motions and accelerations during 25 year cyclone with intact and broken line condition are presented in Table 6-6. In the intact condition, the maximum offset is 19.98 m and maximum heel is 1.91 degree, while in broken line condition the maximum offset is 294.0 m and the maximum heel is 2.26 degree. The maximum offset during broken line event needs more attention while designing power cable. The maximum heave ranges for MCF hull is about 1.94 m.

The maximum lateral acceleration at topside is 0.08 g.

The maximum mooring tensions in 25 year cyclone for chain and polyester are listed in Table 6-7 and 6-8, respectively. In intact condition the usage factor of chain is 0.28 and the allowable is 0.6. This means there is 114% margin of chain strength. In broken line condition the margin is about 82%.

For the polyester segment, the usage factors in intact and broken line condition are 0.24 and 0.38, respectively. Those usage factors translate into 129% and 84% of margin in intact and broken line conditions, respectively.

In intact condition, the maximum horizontal and vertical anchor loads during these events are around 3,807 kN and 1,364 kN, respectively. In broken line condition, the maximum horizontal and vertical anchor loads during these events are around 2,452 kN and 3,890 kN, respectively

Summary statistic of motions, acceleration, mooring tension and anchor loads during pilot test are shown Appendix B. Detail anchor loads are tabulated in Appendix D.

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Table 6-6 Motion and Acceleration – Pipe Manufacturing

Motions and Accelerations							
Environment	Mooring Condition	Hull Condition	Hull Max Offset	Hull Min Heave	Hull Max Heave	Hull Max Heel	Lat. Acc @Topside
			(m)	(m)	(m)	(deg)	(g)
25 Year Cyclones	Intact	Intact	19.98	-0.63	0.76	1.91	0.08
	Broken Line	Intact	294.00	-0.84	1.11	2.26	0.08

Table 6-7 Mooring Line Tension at Chain – Pipe Manufacturing

Tension @ Chain						
Environment	Mooring Condition	Maximum Tension	Breaking Strength	Usage Factor	Allowable Usage	Margin
		(kN)	(kN)			(%)
25 Year Cyclones	Intact	2953.72	10549.00	0.28	0.60	114.29
	Broken Line	4641.56	10549.00	0.44	0.80	81.82

Table 6-8 Mooring Line Tension at Polyester – Pipe Manufacturing

Tension @ Polyester						
Environment	Mooring Condition	Maximum Tension	Breaking Strength	Usage Factor	Allowable Usage	Margin
		(kN)	(kN)			(%)
25 Year Cyclones	Intact	2852.40	11885.00	0.24	0.55	129.17
	Broken Line	4516.30	11885.00	0.38	0.70	84.21

Table 6-9 Anchor Forces – Pipe Manufacturing

Anchor Forces			
Environment	Mooring Condition	Horizontal Force	Vertical Force
		(kN)	(kN)
25 Year Cyclones	Intact	3807.00	1364.00
	Broken Line	2452.00	3890.00

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Response in Production Configuration

MCF motions and accelerations during 100 year cyclone and 10 year swell with intact and broken line condition are presented in Table 6-10. In 100 year events and intact condition, the maximum offset is 55.08 m and maximum heel is 3.9 degree, while in the broken line condition the maximum offset is 107.5 m and the maximum heel is 4.06 degree. The maximum offset during broken line event in this configuration is less than that of pilot test due to the difference in number of mooring lines. The maximum heave ranges for MCF hull is about 1.94 m.

The maximum lateral acceleration at topside is 0.19 g in 100 year events. In 10 year events, the maximum lateral accelerations are 0.18 g.

The maximum mooring tensions in 100 year cyclone for chain and polyester are listed in Table 6-11 and 6-12, respectively. In intact condition the usage factor of chain is 0.44 and the allowable is 0.6. This means there is 36% margin of chain strength. In broken line condition the margin is about 9.6%.

For the polyester segment, the usage factors in intact and broken line condition are 0.37 and 0.63, respectively. Those usage factors translate into 49% and 11% of margin in intact and broken line conditions, respectively.

In intact condition, the maximum horizontal and vertical anchor loads during these events are around 3,704 kN and 2,308 kN, respectively. In broken line condition, the maximum horizontal and vertical anchor loads during these events are around 6,319 kN and 4,007 kN, respectively

Summary statistic of motions, acceleration, mooring tension and anchor loads during production are shown Appendix C. Detail anchor loads are tabulated in Appendix D.

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Table 6-10 Motion and Acceleration – Pipe Manufacturing

Motions and Accelerations							
Environment	Mooring Condition	Hull Condition	Hull Max Offset	Hull Min Heave	Hull Max Heave	Hull Max Heel	Lat. Acc @Topside
			(m)	(m)	(m)	(deg)	(g)
100 Year Cyclones	Intact	Intact	55.08	-2.35	1.98	3.90	0.19
	Broken Line	Intact	107.50	-2.30	2.02	4.06	0.18
10 Year Swell	Intact	Intact	8.77	-1.56	1.65	3.90	0.13
	Broken Line						

Table 6-11 Mooring Line Tension at Chain – Pipe Manufacturing

Tension @ Chain						
Environment	Mooring Condition	Maximum Tension	Breaking Strength	Usage Factor	Allowable Usage	Margin
		(kN)	(kN)			
100 Year Cyclones	Intact	4641.56	10549.00	0.44	0.60	36.36
	Broken Line	7700.77	10549.00	0.73	0.80	9.59
10 Year Swell	Intact	2320.78	10549.00	0.22	0.60	172.73
	Broken Line					

Table 6-12 Mooring Line Tension at Polyester – Pipe Manufacturing

Tension @ Polyester						
Environment	Mooring Condition	Maximum Tension	Breaking Strength	Usage Factor	Allowable Usage	Margin
		(kN)	(kN)			(%)
100 Year Cyclones	Intact	4397.45	11885.00	0.37	0.55	48.65
	Broken Line	7487.55	11885.00	0.63	0.70	11.11
10 Year Swell	Intact	2139.30	11885.00	0.18	0.70	288.89
	Broken Line					

Table 6-13 Anchor Forces – Pipe Manufacturing

Anchor Forces			
Environment	Mooring Condition	Horizontal Force	Vertical Force
		(kN)	(kN)
100 Year Cyclones	Intact	3704.00	2308.00
	Broken Line	6319.00	4007.00
10 Year Swell	Intact	1802.00	1004.00
	Broken Line		

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7 SUMMARY AND RECOMMENDATIONS

The global performance and mooring design with CHARM3D has been conducted for MCF with 5.5 m of cell diameter and 23 m draft. Three MCF configurations, pipe manufacturing, pilot test, and production have been investigated.

The global performance has been performed for a wide range of environmental conditions to investigate design values. Three environmental headings (0.0, 45, and 225.0 degrees) and three return periods (100 year events, 25 year events, and 10 year events) were tested.

Various options for hydrodynamic load modeling are available in CHARM3D. For this study the Morrison model combined with frequency-dependent added mass, damping and exciting forces from diffraction and radiation program has been used.

The drag coefficients for MCF hull were derived from model tests of similar hull. The added mass and damping coefficients as well as exciting forces were computed using WAMIT. The wind effective area for wind force calculation was calculated from spreadsheet.

Based on the numerical results, motions and mooring design seems to be manageable. Mooring chain and polyester line may need to be upgraded to higher diameter if more margins are needed. The maximum offset in broken line condition during pilot test need attention while designing power cable to shore. Transient motions due to broken line events may affect the design of cold water pipe.

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8 REFERENCES

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2. Davies, R, “OTEC MCF Weight Report”, Horton Wison Deepwater Inc., 2010.
3. Halkyard, J.E, “Design Basis for a Moored OTEC Pilot Power Plant (Barbers Point)”, Working Version for Pre-FEED, Feb 10, 2010.
4. “Topside Drawing No. H09102-H-0013 Rev. B and H09102-H-0014 Rev. B” Houston Offshore Engineering, 2010
5. Wamit Inc., “WAMIT User Manual” 2006
6. Newman, “Second-Order Slowly-Varying Forces On Vessels In Irregular Waves” Symp. On Dynamics of Marine Vehicles and Structures in Waves, London, 1974.

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APPENDIX A: Global Performance Results During Pipe Fabrication

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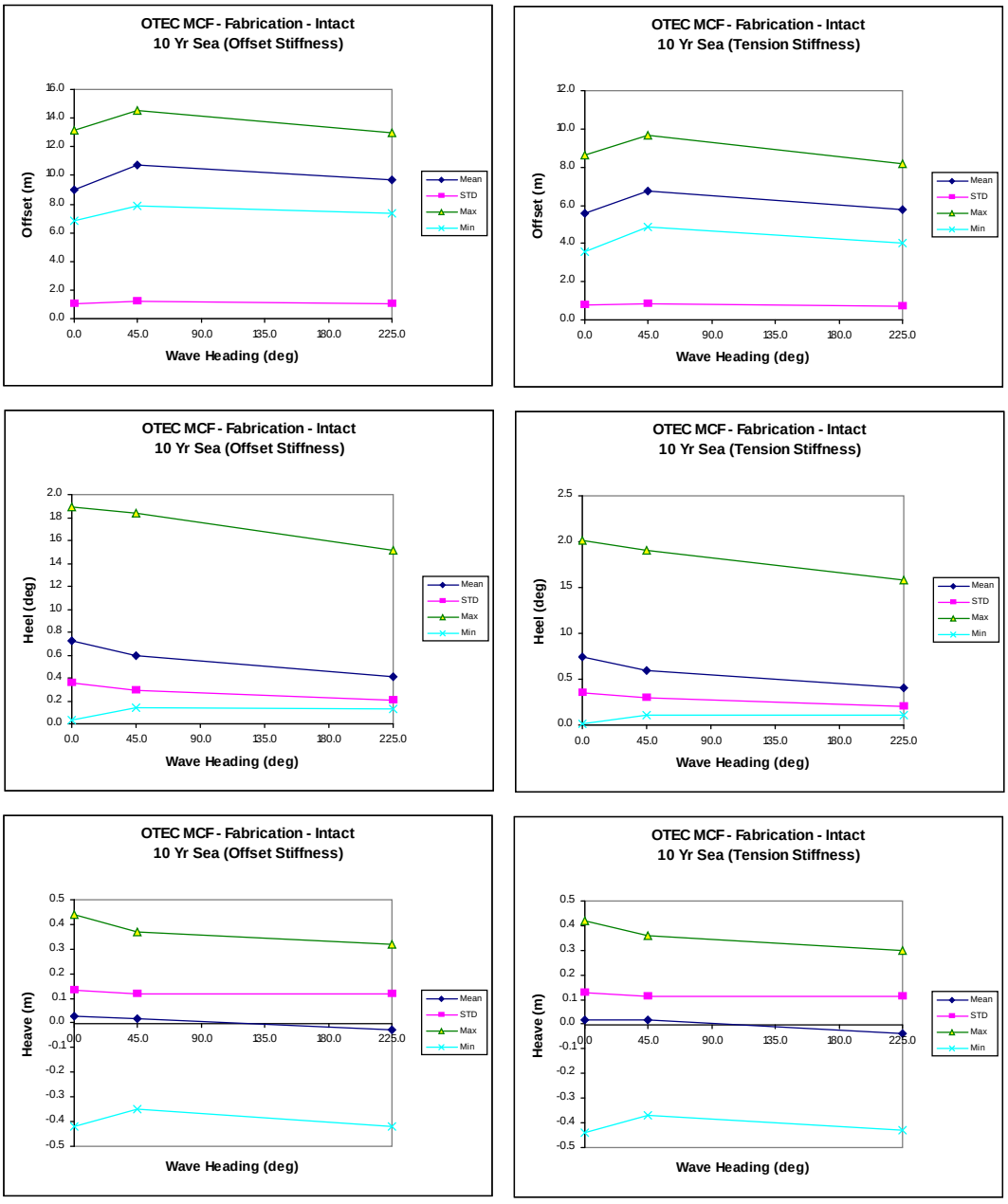


Figure A-1 Motion Summary of MCF Hull in Intact – 10 Year Sea

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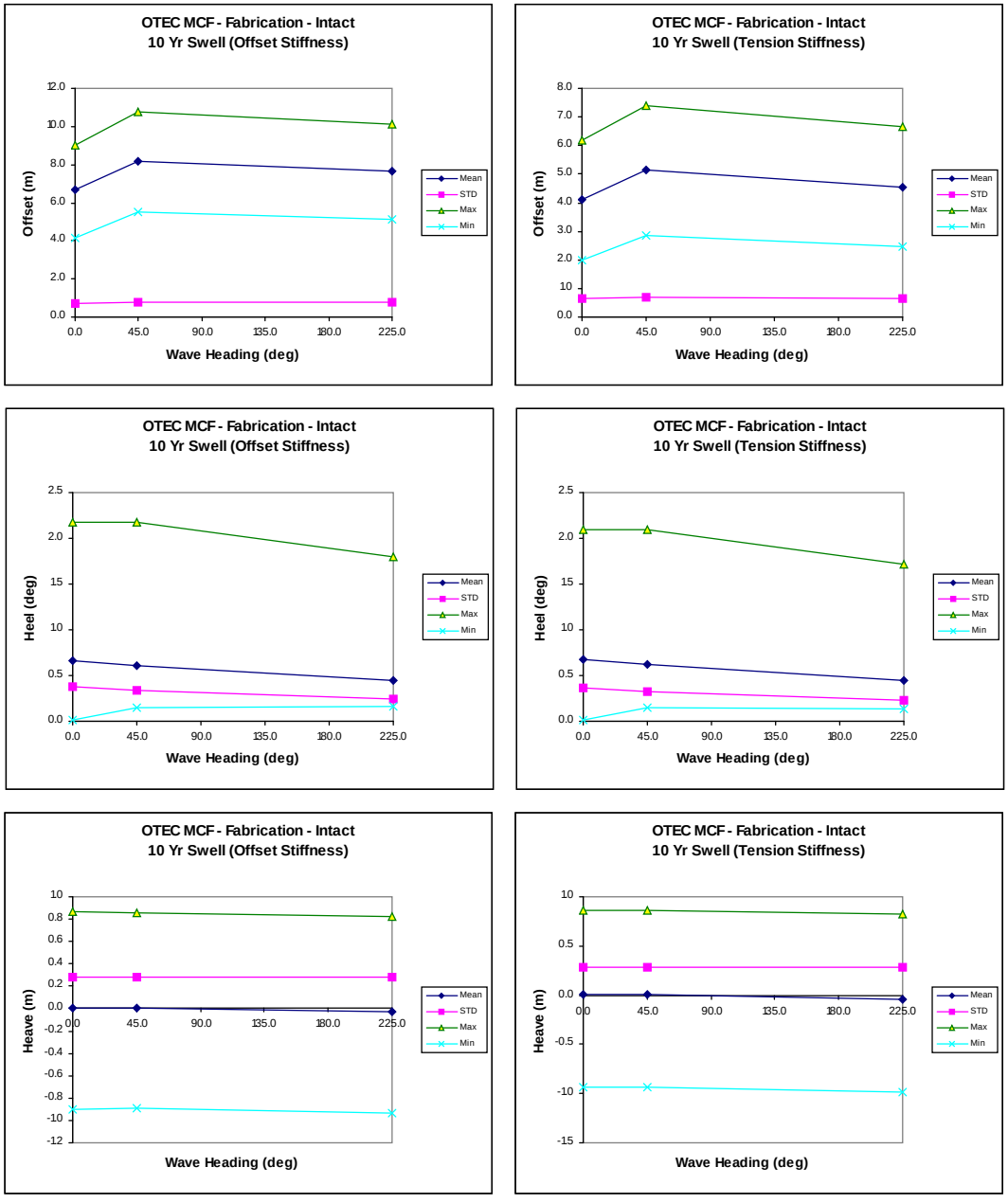


Figure A-2 Motion Summary of MCF Hull in Intact – 10 Year Swell

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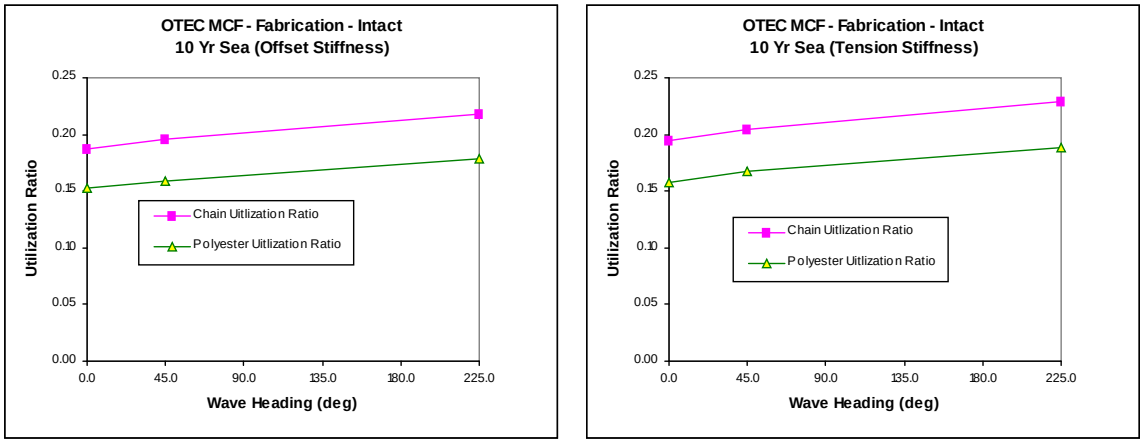


Figure A-3 Mooring Tension Summary of MCF Hull in Intact – 10 Year Sea

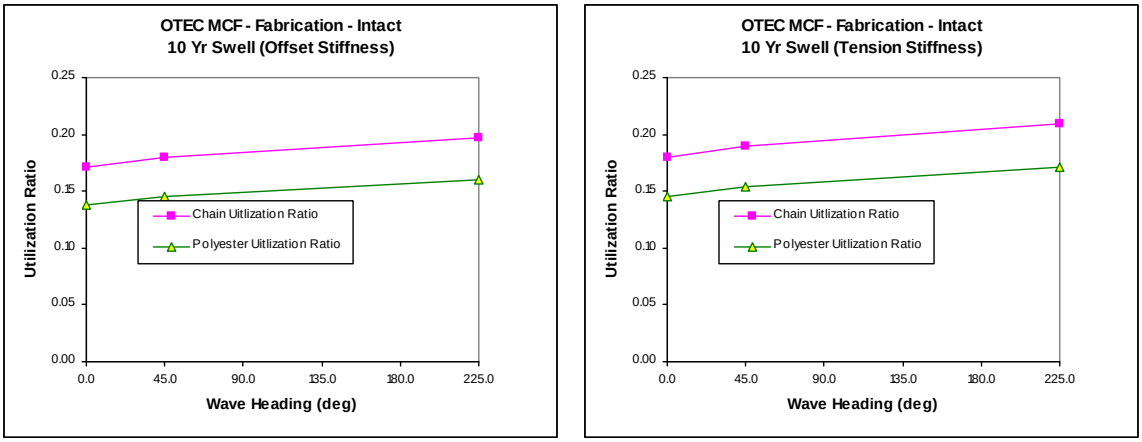


Figure A-4 Mooring Tension Summary of MCF Hull in Intact – 10 Year Swell

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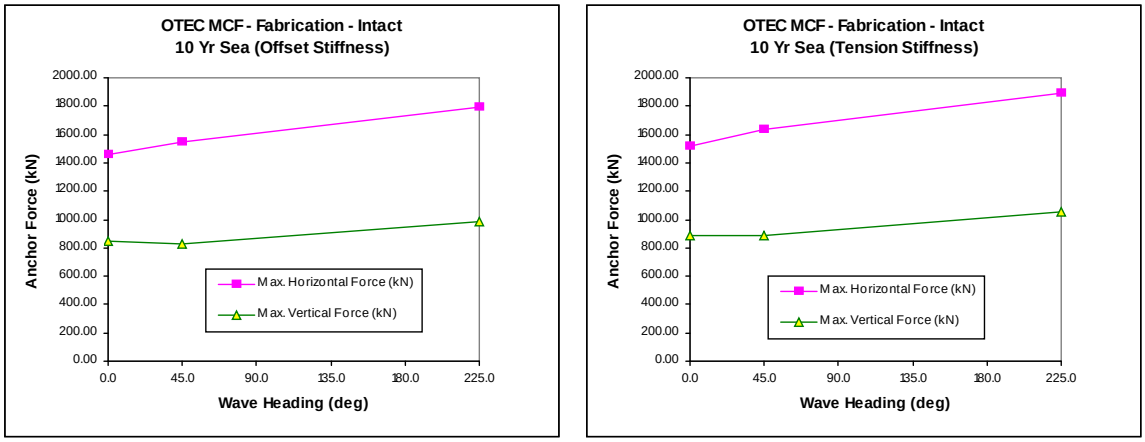


Figure A-5 Anchor Load Summary of MCF Hull in Intact – 10 Year Sea

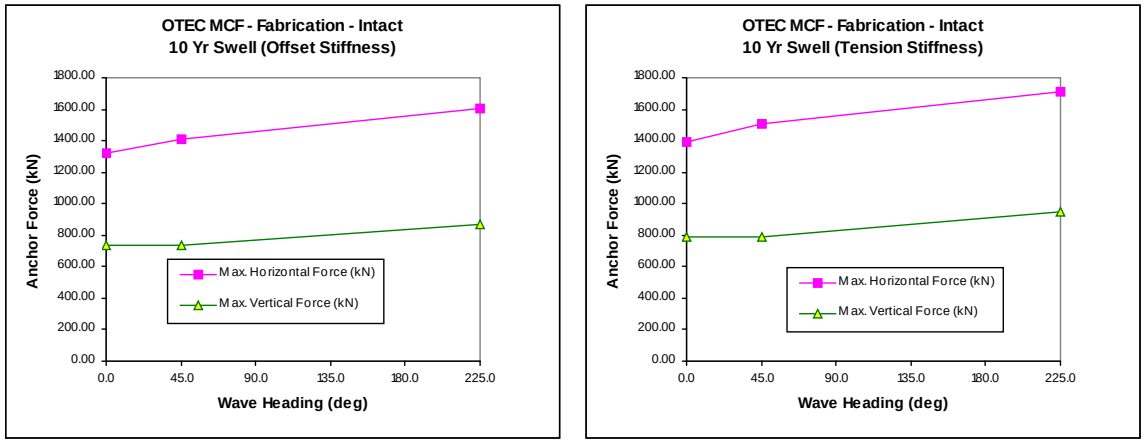


Figure A-6 Anchor Load Summary of MCF Hull in Intact – 10 Year Swell

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APPENDIX B: Global Performance Results During Pilot Test

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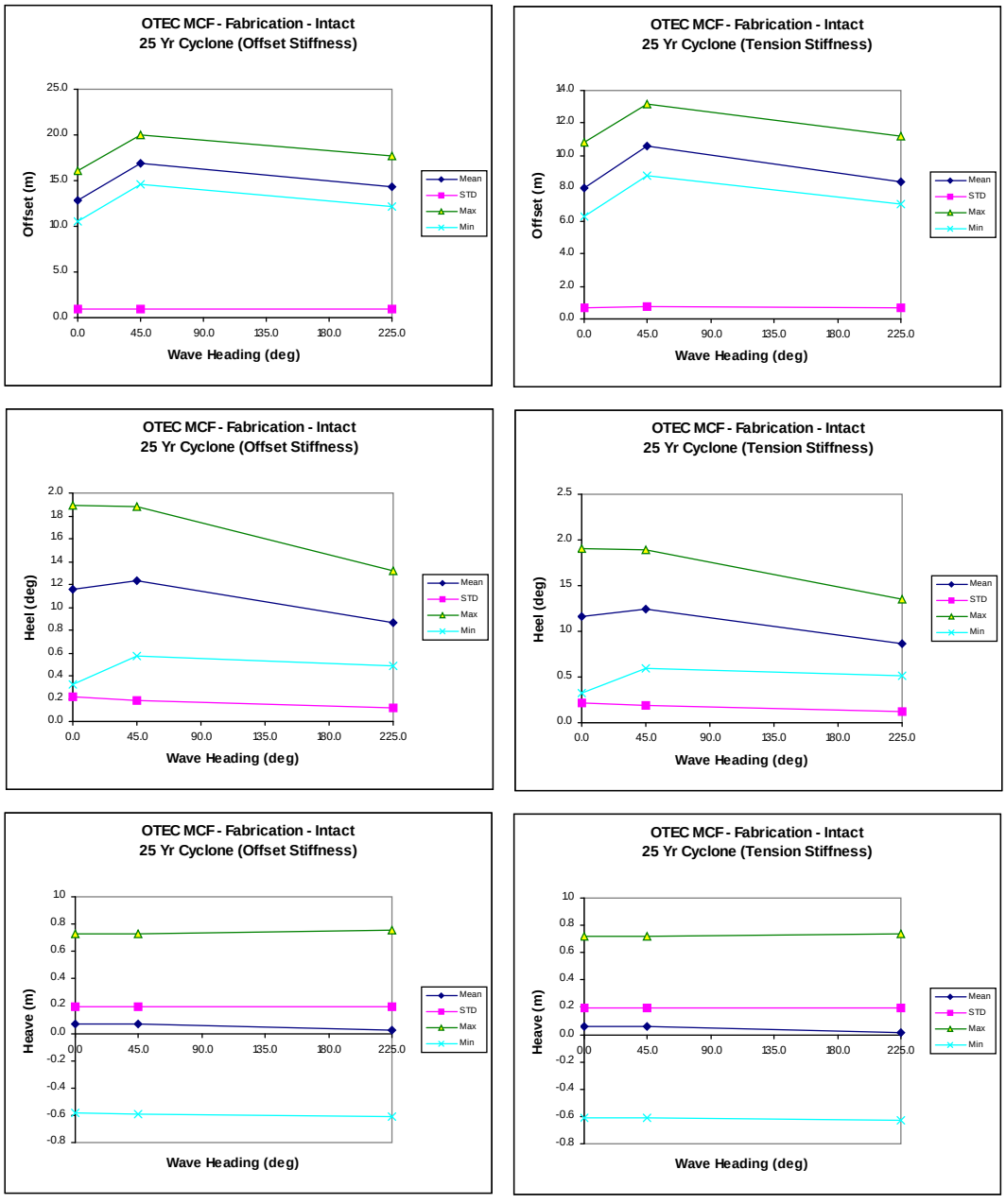


Figure B-1 Motion Summary of MCF Hull in Intact – 25 Year Cyclone

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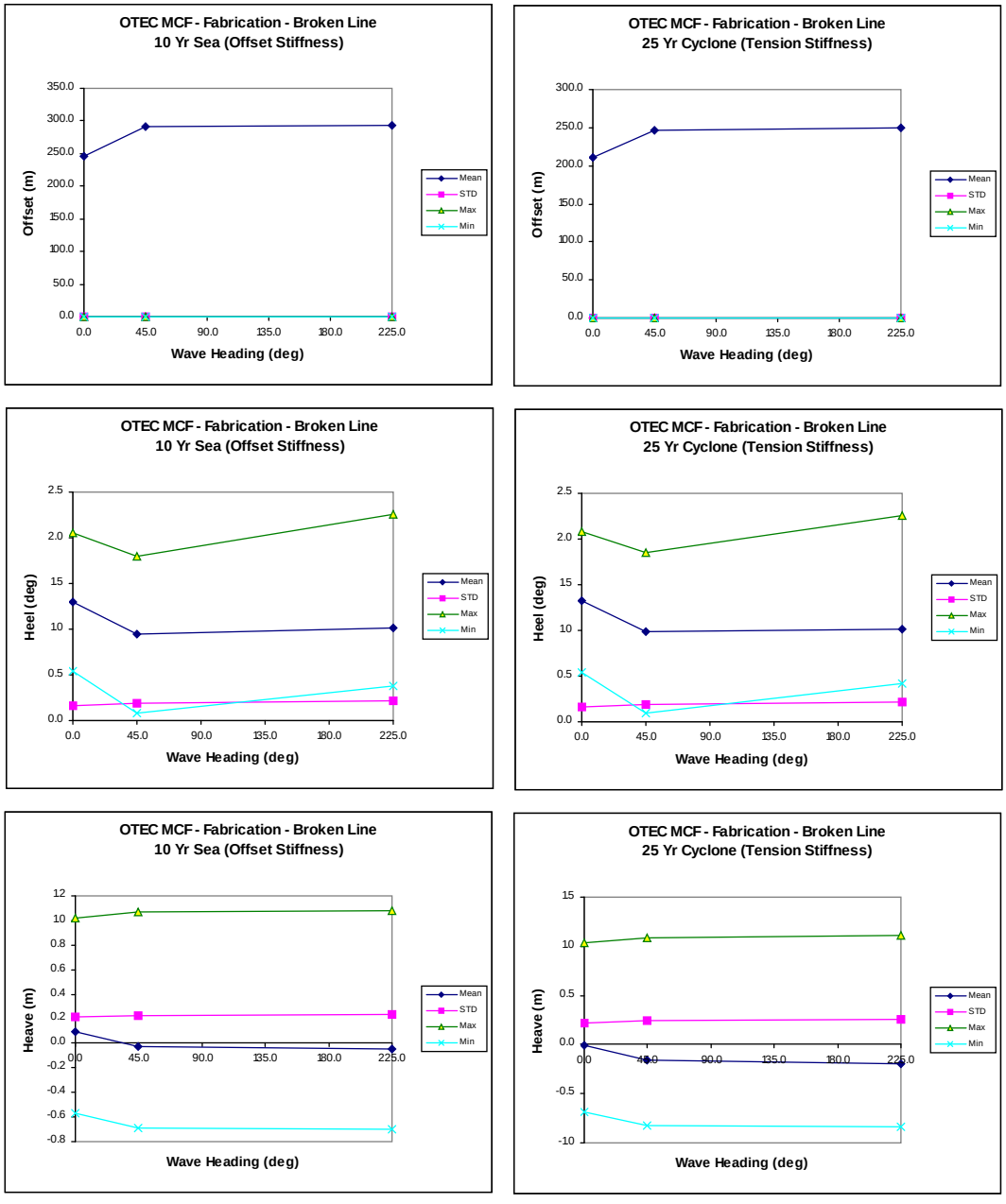


Figure B-2 Motion Summary of MCF Hull in Broken Line – 25 Year Cyclone

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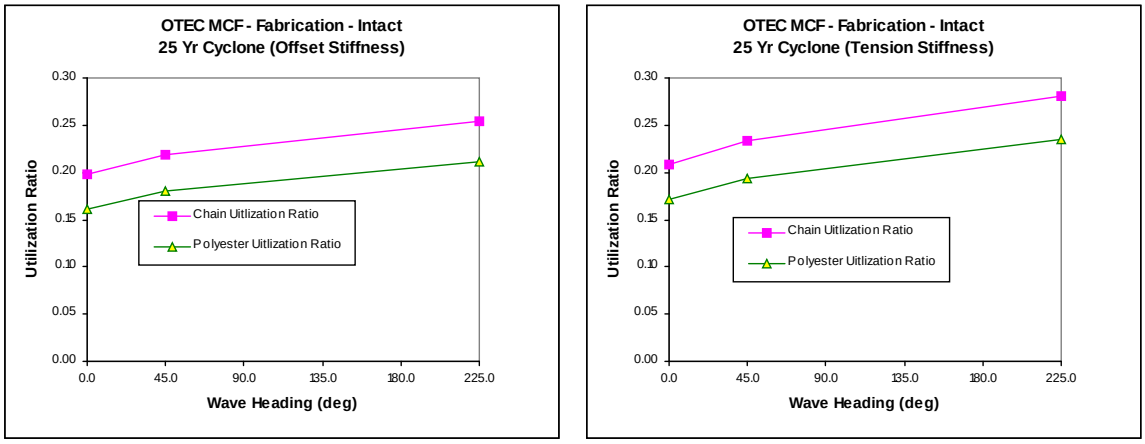


Figure B-3 Mooring Tension Summary of MCF Hull in Intact – 25 Year Cyclone

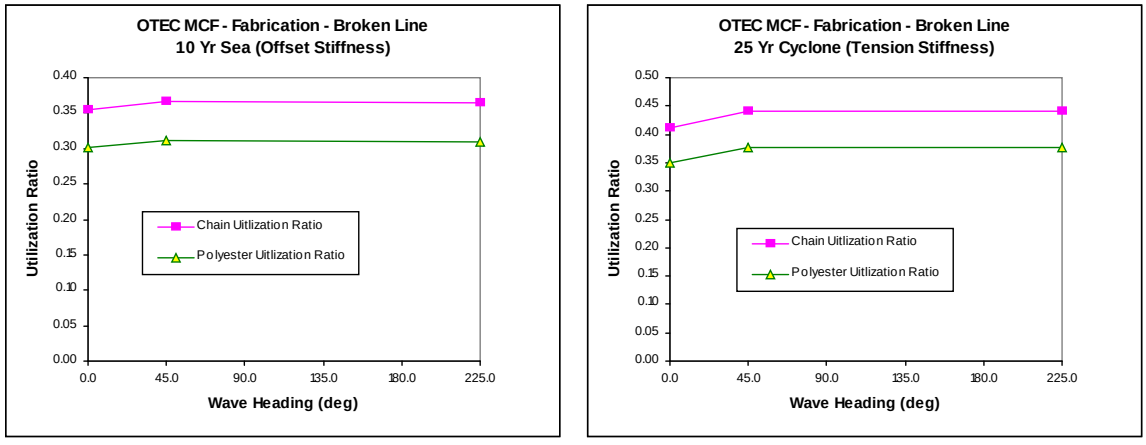


Figure B-4 Mooring Tension Summary of MCF Hull in Broken Line – 25 Year Cyclone

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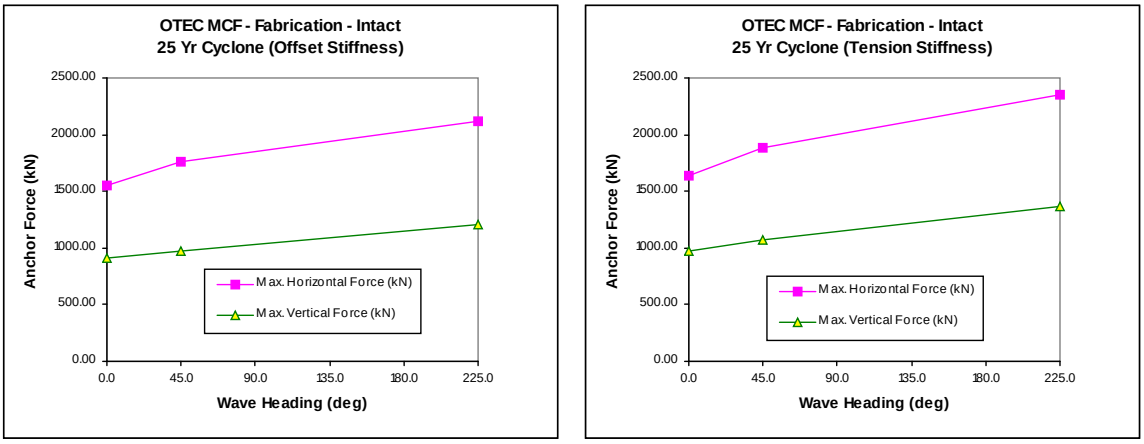


Figure B-5 Anchor Load Summary of MCF Hull in Intact – 10 Year Sea

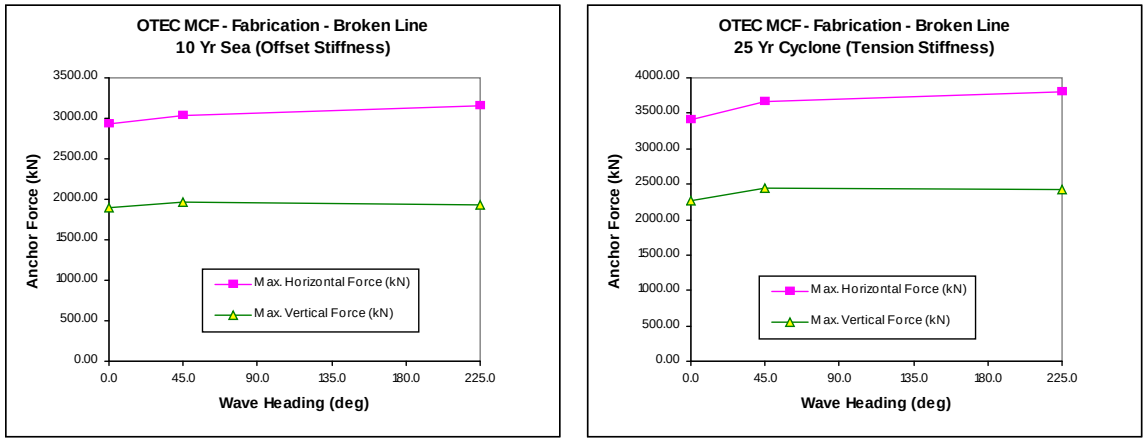


Figure B-6 Anchor Load Summary of MCF Hull in Intact – 10 Year Swell

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APPENDIX C: Global Performance Results During Production

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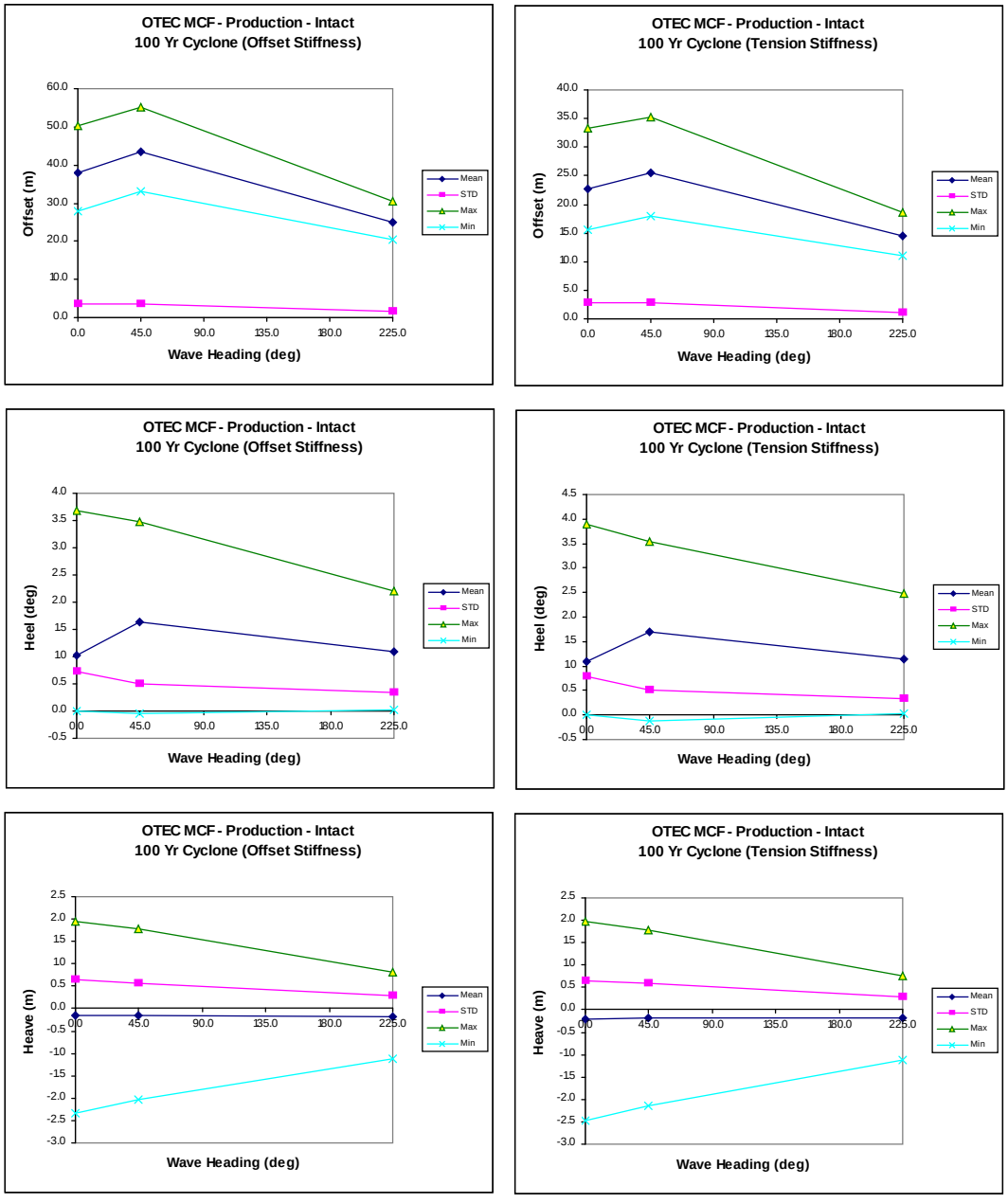


Figure C-1 Motion Summary of MCF Hull in Intact – 100 Year Cyclone

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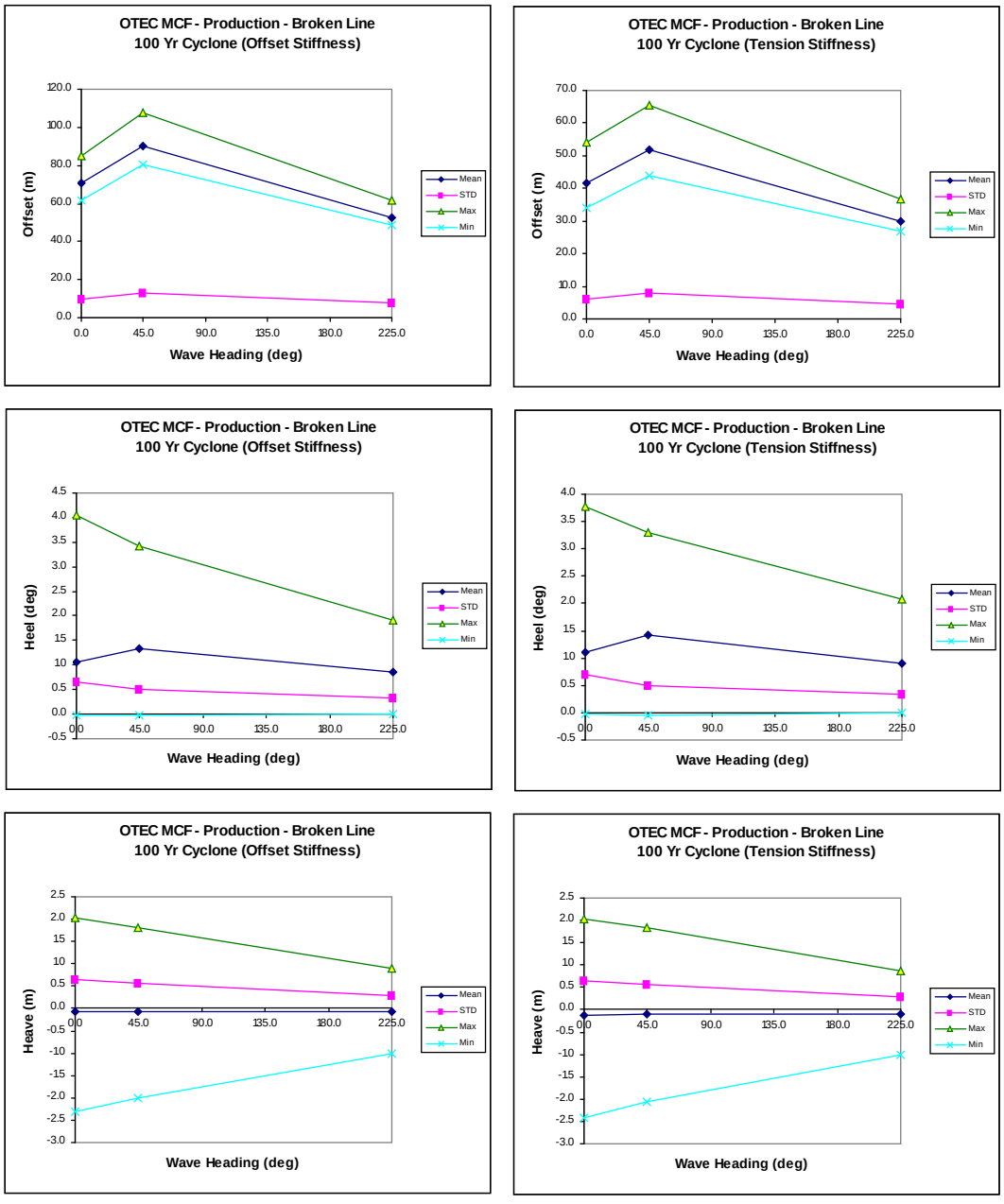


Figure C-2 Motion Summary of MCF Hull in Broken Line – 100 Year Cyclone

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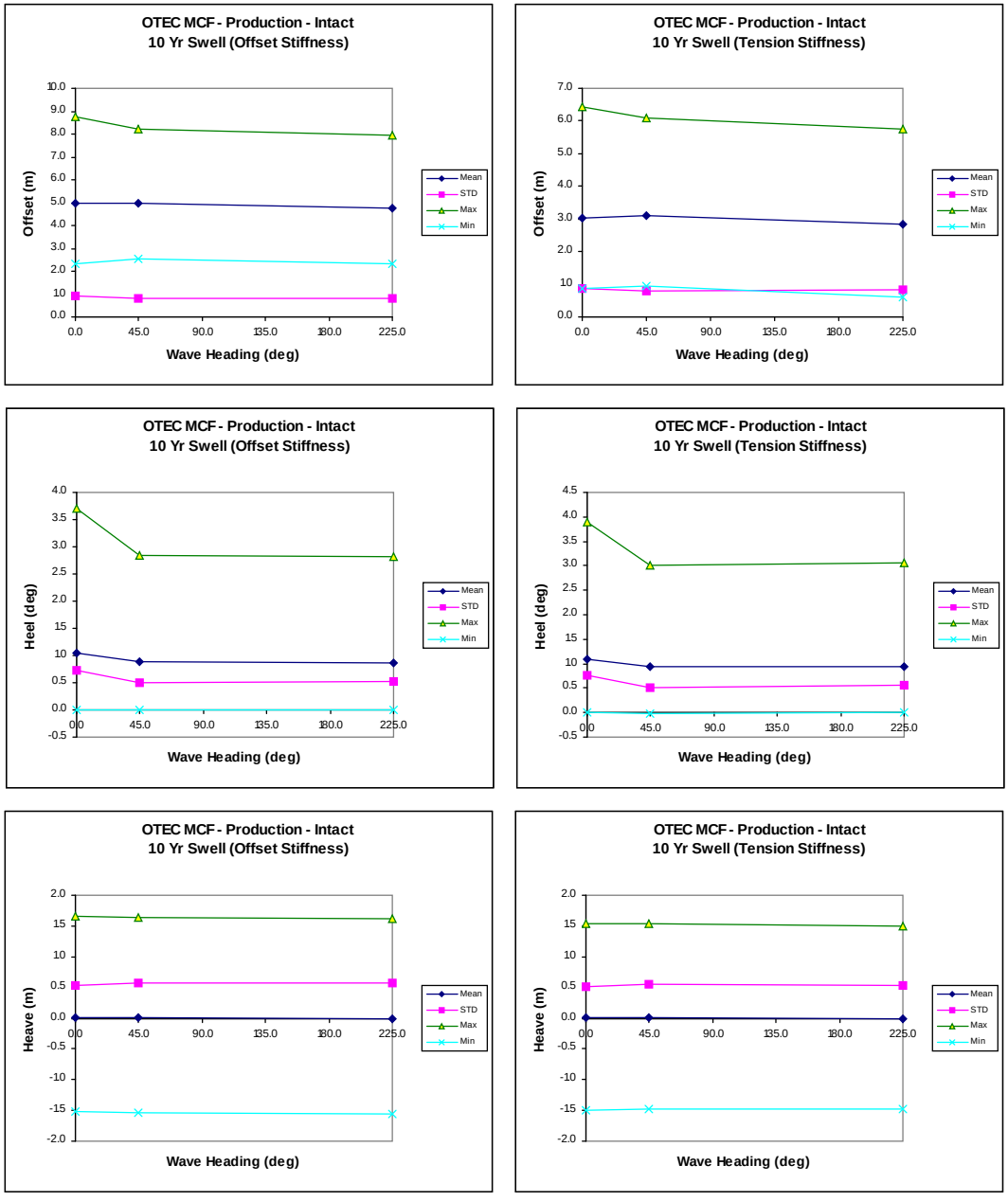


Figure C-3 Motion Summary of MCF Hull in Intact – 10 Year Swell

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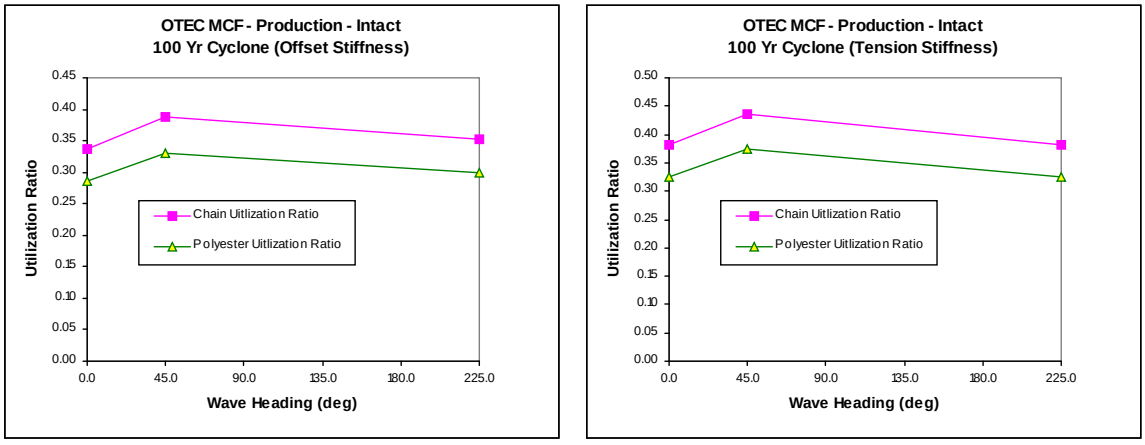


Figure C-4 Mooring Tension Summary of MCF Hull in Intact – 100 Year Cyclone

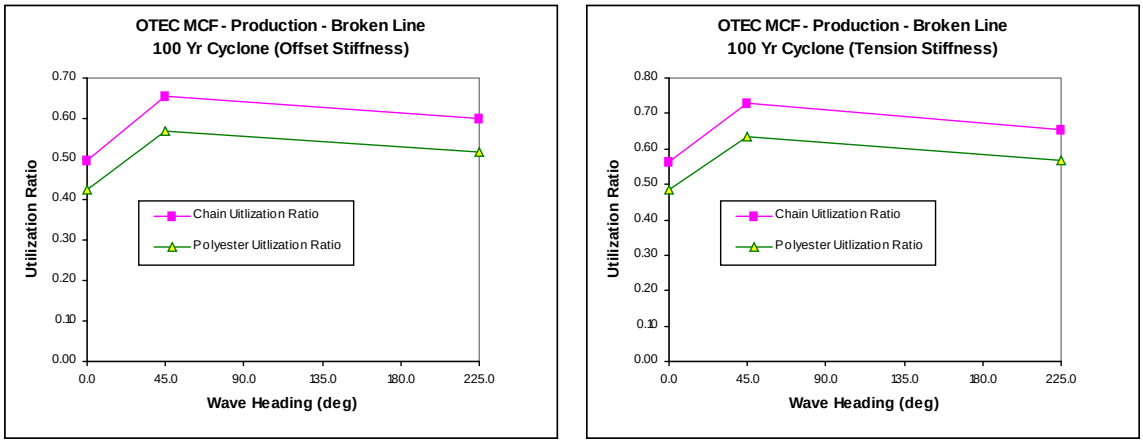


Figure C-5 Mooring Tension Summary of MCF Hull in Broken Line – 100 Year Cyclone

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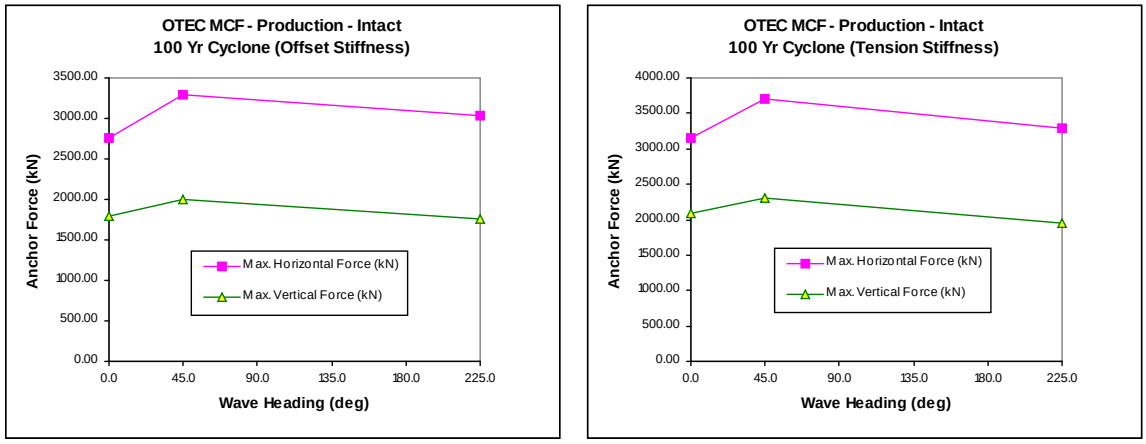


Figure C-6 Anchor Load Summary of MCF Hull in Intact – 100 Year Cyclone

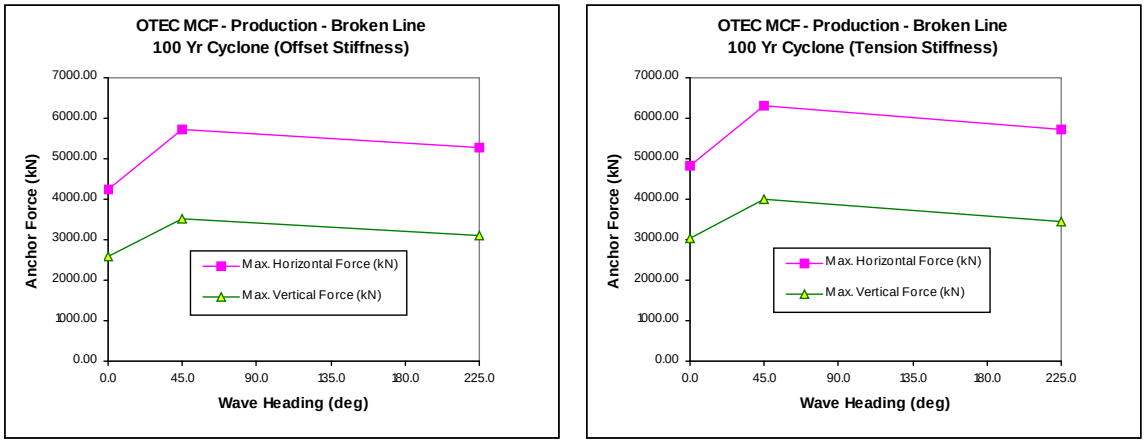


Figure C-7 Anchor Load Summary of MCF Hull in Broken Line – 100 Year Cyclone

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APPENDIX D: Detail Anchor Loads

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MCF Mooring Tension		10 yr Sea Storm Offset Case 1	10 yr Sea Storm Offset Case 2	10 yr Sea Storm Offset Case 3	10 yr Swell Storm Offset Case 4	10 yr Swell Storm Offset Case 5	10 yr Swell Storm Offset Case 6
Simulation time	sec	3699	3699	3699	3699	3699	3699
Directions							
Waves	deg	0.00	45.00	225.00	0.00	45.00	225.00
Wind	deg	0.00	45.00	225.00	0.00	45.00	225.00
Current	deg	0.00	45.00	225.00	0.00	45.00	225.00
SurGace Current Speed	Gt/sec	0.48	0.48	0.48	0.48	0.48	0.48
Wave (m)	Height	6.36	6.36	6.36	6.36	6.36	6.36
	Hs	4.20	4.20	4.20	4.20	4.20	4.20
	Tp	9.19	9.19	9.19	9.19	9.19	9.19
	STD	1.04	1.04	1.04	1.04	1.04	1.04
	Hs/STD	4.04	4.04	4.04	4.04	4.04	4.04
Wind Speed (1 Hr | 10 m)	kts	0.00	0.00	0.00	0.00	0.00	0.00
Mooring 1 - Hor-X (N)	Mean	541545.00	454906.00	1214638.00	548713.00	469734.00	1236652.00
	STD	26428.00	28031.00	47245.00	30603.00	30380.00	60681.00
	Max	605025.00	525379.00	1372213.00	638723.00	561163.00	1445827.00
	Min	444023.00	363839.00	1104530.00	427336.00	359124.00	1077097.00
	Tz	27.23	32.50	64.56	16.27	19.65	37.70
Mooring 2 - Hor-X (N)	Mean	-1010618.00	-780077.00	-813753.00	-1020586.00	-778422.00	-815553.00
	STD	27690.00	6038.00	6593.00	35657.00	8955.00	10001.00
	Max	-1010416.00	-757939.00	-794428.00	-919062.00	-746282.00	-780129.00
	Min	-1121715.00	-799970.00	-836096.00	-1166514.00	-805592.00	-852616.00
	Tz	33.24	21.87	20.31	21.67	16.23	16.57
Mooring 3 - Hor-X (N)	Mean	-984355.00	-1073822.00	-595460.00	-991609.00	-1092923.00	-612775.00
	STD	23865.00	32916.00	19061.00	30436.00	42544.00	21032.00
	Max	-928079.00	-994214.00	-528123.00	-912457.00	-997659.00	-529357.00
	Min	-1080156.00	-1182670.00	-641070.00	-1120192.00	-1248258.00	-673221.00
	Tz	33.25	55.25	33.21	22.47	44.95	21.90
Mooring 4 - Hor-X (N)	Mean	565765.00	821274.00	772283.00	576059.00	824302.00	769105.00
	STD	24688.00	7818.00	7968.00	28819.00	11447.00	11781.00
	Max	625593.00	848259.00	797648.00	664116.00	868684.00	808081.00
	Min	473226.00	797440.00	742655.00	460859.00	787847.00	729898.00
	Tz	27.03	23.04	25.61	15.51	16.59	17.54
Mooring 1 - Hor-Y (N)	Mean	459368.00	380245.00	1023229.00	463996.00	393187.00	1040277.00
	STD	21886.00	23563.00	40094.00	25448.00	25522.00	51229.00
	Max	512052.00	439378.00	1156256.00	539031.00	469847.00	1216826.00
	Min	377588.00	303988.00	929690.00	362472.00	299856.00	905825.00
	Tz	27.43	32.77	67.03	16.27	19.96	37.70
Mooring 2 - Hor-Y (N)	Mean	840614.00	644044.00	692881.00	851176.00	645794.00	691102.00
	STD	22378.00	5539.00	5950.00	29304.00	7870.00	8625.00
	Max	931018.00	661219.00	713321.00	969831.00	668782.00	723232.00
	Min	790161.00	623938.00	675175.00	767169.00	617136.00	662821.00
	Tz	32.11	22.22	24.34	21.36	16.56	17.63
Mooring 3 - Hor-Y (N)	Mean	-819966.00	-903398.00	-498177.00	-827825.00	-918592.00	-513187.00
	STD	19357.00	27899.00	16035.00	25049.00	35907.00	17658.00
	Max	-773842.00	-835813.00	-441782.00	-762740.00	-838196.00	-443115.00
	Min	-898249.00	-995680.00	-536673.00	-935209.00	-1049626.00	-563848.00
	Tz	32.94	54.35	33.83	21.67	45.50	21.77
Mooring 4 - Hor-Y (N)	Mean	-479897.00	-701575.00	-637438.00	-487153.00	-700279.00	-638304.00
	STD	20437.00	7248.00	7051.00	23984.00	10084.00	10135.00
	Max	-402143.00	-680096.00	-611819.00	-390837.00	-668626.00	-603446.00
	Min	-529610.00	-725760.00	-658983.00	-560587.00	-739686.00	-671859.00
	Tz	26.30	27.36	26.33	15.49	17.85	17.51
Mooring 1 - Vert (N)	Mean	269872.00	191573.00	851666.00	274792.00	203880.00	873318.00
	STD	22615.00	24134.00	40818.00	25796.00	25569.00	52797.00
	Max	322944.00	251063.00	989264.00	349180.00	277848.00	1058258.00
	Min	187390.00	115183.00	756300.00	177300.00	114684.00	739468.00
	Tz	31.42	47.18	66.66	17.84	26.76	42.43
Mooring 2 - Vert (N)	Mean	740132.00	519709.00	561792.00	752336.00	519470.00	562109.00
	STD	25803.00	5925.00	6408.00	33618.00	8562.00	9502.00
	Max	844127.00	538208.00	583524.00	884914.00	545504.00	597312.00
	Min	739931.00	497505.00	542704.00	656916.00	488278.00	529167.00
	Tz	35.95	23.49	22.47	25.08	16.64	17.71
Mooring 3 - Vert (N)	Mean	651077.00	735524.00	301914.00	659709.00	754599.00	317177.00
	STD	21251.00	29811.00	17221.00	27347.00	38771.00	18760.00
	Max	738943.00	830958.00	342532.00	774750.00	890726.00	370556.00
	Min	600847.00	664891.00	243382.00	587736.00	669637.00	244968.00
	Tz	35.95	59.08	38.63	23.75	49.17	26.38
Mooring 4 - Vert (N)	Mean	284250.00	508010.00	455495.00	291898.00	509135.00	454072.00
	STD	21006.00	7008.00	7005.00	24191.00	9938.00	10140.00
	Max	332745.00	531381.00	477108.00	365424.00	548196.00	488205.00

Figure D-1 Anchor Load Summary – Mooring Intact – Pipe Fabrication

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MCF Mooring Tension		10 yr Sea Storm Tension Case 7	10 yr Sea Storm Tension Case 8	10 yr Sea Storm Tension Case 9	10 yr Swell Storm Tension Case 10	10 yr Swell Storm Tension Case 11	10 yr Swell Storm Tension Case 12
Simulation time	sec	3699	3699	3699	3699	3699	3699
Directions							
Waves	deg	0.00	45.00	225.00	0.00	45.00	225.00
Wind	deg	0.00	45.00	225.00	0.00	45.00	225.00
Current	deg	0.00	45.00	225.00	0.00	45.00	225.00
SurGace Current Speed	Gt/sec	0.48	0.48	0.48	0.48	0.48	0.48
Wave (m)	Height	5.29	5.29	5.29	5.29	5.29	5.29
	Hs	3.80	3.80	3.80	3.80	3.80	3.80
	Tp	18.01	18.01	18.01	18.01	18.01	18.01
	STD	0.94	0.94	0.94	0.94	0.94	0.94
	Hs/STD	4.04	4.04	4.04	4.04	4.04	4.04
Wind Speed (1 Hr | 10 m)	kts	0.00	0.00	0.00	0.00	0.00	0.00
Mooring 1 - Hor-X (N)	Mean	598723.00	514900.00	1121858.00	602196.00	523253.00	1137515.00
	STD	22959.00	30587.00	33386.00	35191.00	45870.00	55361.00
	Max	666777.00	601510.00	1227520.00	701696.00	648995.00	1309998.00
	Min	520194.00	407104.00	1001434.00	482367.00	366685.00	953422.00
	Tz	17.01	17.85	21.59	15.35	15.03	17.81
Mooring 2 - Hor-X (N)	Mean	-953419.00	-782966.00	-809529.00	-960129.00	-781954.00	-810978.00
	STD	20679.00	10692.00	9424.00	35562.00	21167.00	19127.00
	Max	-877331.00	-749052.00	-774845.00	-842564.00	-713680.00	-746341.00
	Min	-1017096.00	-820412.00	-838059.00	-1071851.00	-848208.00	-870893.00
	Tz	18.45	15.69	15.44	16.61	15.17	14.91
Mooring 3 - Hor-X (N)	Mean	-933859.00	-1005973.00	-631873.00	-938381.00	-1019025.00	-642896.00
	STD	18901.00	24327.00	21892.00	35553.00	42936.00	46947.00
	Max	-864945.00	-920371.00	-562040.00	-825328.00	-878132.00	-504449.00
	Min	-990093.00	-1080849.00	-696047.00	-1047006.00	-1151690.00	-785048.00
	Tz	18.09	20.10	17.32	16.61	17.57	16.09
Mooring 4 - Hor-X (N)	Mean	616983.00	815690.00	776886.00	622933.00	818251.00	774557.00
	STD	22969.00	10412.00	11867.00	37188.00	18608.00	20835.00
	Max	683242.00	847357.00	818802.00	724027.00	876581.00	841060.00
	Min	538888.00	776767.00	738254.00	493536.00	754873.00	706349.00
	Tz	16.96	15.48	15.53	15.10	14.91	15.05
Mooring 1 - Hor-Y (N)	Mean	507013.00	430703.00	944403.00	508882.00	438151.00	956492.00
	STD	19409.00	25712.00	28046.00	29536.00	38501.00	46406.00
	Max	565950.00	503603.00	1033332.00	594633.00	543136.00	1101175.00
	Min	441651.00	340098.00	843257.00	408476.00	306654.00	802030.00
	Tz	16.78	17.77	21.72	15.35	15.10	17.98
Mooring 2 - Hor-Y (N)	Mean	794355.00	648238.00	687799.00	801388.00	649634.00	686601.00
	STD	16968.00	8120.00	9025.00	29433.00	16839.00	17107.00
	Max	846072.00	675685.00	716758.00	893531.00	701396.00	742743.00
	Min	731108.00	621700.00	655970.00	703115.00	594485.00	630359.00
	Tz	18.24	15.60	15.75	16.79	15.19	15.16
Mooring 3 - Hor-Y (N)	Mean	-778866.00	-845850.00	-528898.00	-783774.00	-856221.00	-538543.00
	STD	15176.00	20579.00	18430.00	29034.00	36202.00	39421.00
	Max	-722593.00	-773677.00	-470233.00	-690688.00	-737589.00	-422357.00
	Min	-824012.00	-909173.00	-582889.00	-872121.00	-968274.00	-657679.00
	Tz	18.27	19.99	17.40	16.61	17.66	16.09
Mooring 4 - Hor-Y (N)	Mean	-522414.00	-694604.00	-642842.00	-526409.00	-693960.00	-643529.00
	STD	19217.00	9990.00	9192.00	31045.00	16968.00	16549.00
	Max	-457869.00	-657888.00	-611741.00	-418295.00	-637142.00	-588812.00
	Min	-578925.00	-725492.00	-674779.00	-611967.00	-749152.00	-697124.00
	Tz	16.67	15.51	15.55	15.03	14.86	15.23
Mooring 1 - Vert (N)	Mean	319973.00	244652.00	771086.00	322003.00	251411.00	786306.00
	STD	19128.00	22594.00	30283.00	28008.00	31477.00	49796.00
	Max	378845.00	316255.00	867672.00	411362.00	348393.00	944448.00
	Min	258397.00	169188.00	662801.00	230443.00	146147.00	622881.00
	Tz	17.84	19.15	20.50	16.16	15.68	17.72
Mooring 2 - Vert (N)	Mean	686303.00	523282.00	557045.00	694314.00	523276.00	557458.00
	STD	18082.00	8179.00	8269.00	31703.00	16518.00	16187.00
	Max	740292.00	550896.00	582211.00	791937.00	574644.00	609306.00
	Min	617564.00	496157.00	526997.00	586466.00	468675.00	503659.00
	Tz	19.19	16.08	15.74	17.01	15.31	15.22
Mooring 3 - Vert (N)	Mean	605767.00	673630.00	335322.00	611013.00	686336.00	345177.00
	STD	14219.00	19349.00	15897.00	26072.00	33272.00	31614.00
	Max	649642.00	736689.00	383690.00	690400.00	789366.00	434914.00
	Min	550977.00	603386.00	283795.00	522241.00	572614.00	249681.00
	Tz	18.79	22.51	18.86	17.07	18.08	16.60
Mooring 4 - Vert (N)	Mean	328845.00	502182.00	460117.00	333101.00	503342.00	459086.00
	STD	18185.00	8632.00	8831.00	27812.00	15647.00	16243.00
	Max	383777.00	528758.00	489892.00	419534.00	552150.00	513062.00

Figure D-2 Anchor Load Summary – Mooring Intact – Pipe Fabrication (Cont')

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		25 yr Cyclone Storm Offset	25 yr Cyclone Storm Offset	25 yr Cyclone Storm Offset	25 yr Cyclone Storm Offset	25 yr Cyclone Storm Offset	25 yr Cyclone Storm Offset
MCF Mooring Tension		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Simulation time	sec	3699	3699	3699	3699	3699	mean wind
Directions							
Waves	deg	0.00	45.00	225.00	0.00	45.00	225.00
Wind	deg	0.00	45.00	225.00	0.00	45.00	225.00
Current	deg	0.00	45.00	225.00	0.00	45.00	225.00
SurGace Current Speed	Gt/sec	0.72	0.72	0.72	0.72	0.72	0.72
Wave (m)	Height	6.78	6.78	6.78	6.78	6.78	6.78
	Hs	4.30	4.30	4.30	4.30	4.30	4.30
	Tp	12.03	12.03	12.03	12.03	12.03	12.03
	STD	1.07	1.07	1.07	1.07	1.07	1.07
	Hs/STD	4.02	4.02	4.02	4.02	4.02	4.02
Wind Speed (1 Hr | 10 m)	kts	0.00	0.00	0.00	0.00	0.00	0.00
Mooring 1 - Hor-X (N)	Mean	456617.00	340627.00	1426434.00	471423.00	370096.00	1462772.00
	STD	23491.00	20360.00	46870.00	38772.00	31762.00	67799.00
	Max	531919.00	410837.00	1618713.00	592207.00	493943.00	1800834.00
	Min	366414.00	268648.00	1320990.00	333216.00	264901.00	1316082.00
	Tz	14.08	14.14	31.89	12.68	12.71	21.86
Mooring 2 - Hor-X (N)	Mean	-1107852.00	-784323.00	-828738.00	-1125963.00	-781672.00	-832598.00
	STD	23994.00	11534.00	13237.00	35090.00	20533.00	22858.00
	Max	-1040785.00	-743888.00	-778719.00	-1034273.00	-719408.00	-735840.00
	Min	-1195906.00	-832904.00	-876999.00	-1262436.00	-862812.00	-907405.00
	Tz	24.77	12.46	14.57	19.95	12.10	12.54
Mooring 3 - Hor-X (N)	Mean	-1073480.00	-1251107.00	-519779.00	-1089176.00	-1288513.00	-548193.00
	STD	20574.00	28566.00	16555.00	30386.00	41742.00	22446.00
	Max	-1015036.00	-1175682.00	-452820.00	-1003269.00	-1177301.00	-462183.00
	Min	-1146494.00	-1347811.00	-564527.00	-1205434.00	-1443565.00	-608131.00
	Tz	25.76	32.20	20.35	19.58	27.65	15.61
Mooring 4 - Hor-X (N)	Mean	487318.00	820243.00	757670.00	505430.00	825280.00	753935.00
	STD	22586.00	17937.00	20542.00	37254.00	33424.00	37216.00
	Max	557944.00	881641.00	846113.00	620287.00	935804.00	906346.00
	Min	400303.00	744773.00	688757.00	368588.00	702021.00	640821.00
	Tz	14.41	11.94	13.32	12.56	11.45	12.26
Mooring 1 - Hor-Y (N)	Mean	389902.00	283449.00	1207480.00	400822.00	308600.00	1235594.00
	STD	19682.00	16967.00	40084.00	32629.00	26482.00	57861.00
	Max	453387.00	341346.00	1373914.00	503388.00	411170.00	1523007.00
	Min	313513.00	222933.00	1118425.00	283990.00	220748.00	1110436.00
	Tz	14.02	14.08	28.80	12.55	12.80	21.34
Mooring 2 - Hor-Y (N)	Mean	917470.00	641452.00	710322.00	936057.00	644212.00	708588.00
	STD	19340.00	9477.00	11362.00	28749.00	16978.00	19491.00
	Max	988206.00	681576.00	751354.00	1047908.00	711203.00	771971.00
	Min	862911.00	607975.00	666728.00	859901.00	592662.00	626443.00
	Tz	23.96	12.26	14.95	19.44	12.18	12.73
Mooring 3 - Hor-Y (N)	Mean	-890980.00	-1052206.00	-434694.00	-906858.00	-1082177.00	-459183.00
	STD	16679.00	23898.00	13873.00	24979.00	34875.00	18869.00
	Max	-843398.00	-988044.00	-379194.00	-836261.00	-988183.00	-387001.00
	Min	-950633.00	-1133379.00	-471915.00	-1002709.00	-1210673.00	-509834.00
	Tz	25.39	35.42	20.69	19.48	28.09	15.35
Mooring 4 - Hor-Y (N)	Mean	-416161.00	-710772.00	-617769.00	-429792.00	-709032.00	-619585.00
	STD	18950.00	15411.00	16552.00	31368.00	28623.00	30375.00
	Max	-342035.00	-645955.00	-561949.00	-314074.00	-602727.00	-526938.00
	Min	-475683.00	-763631.00	-688777.00	-527145.00	-803870.00	-742498.00
	Tz	14.04	11.86	12.99	12.41	11.32	12.17
Mooring 1 - Vert (N)	Mean	197345.00	92787.00	1036236.00	208937.00	117909.00	1072122.00
	STD	18624.00	16162.00	40402.00	28542.00	23662.00	58932.00
	Max	250275.00	142648.00	1201794.00	290171.00	195832.00	1364387.00
	Min	125178.00	33833.00	945581.00	106050.00	43041.00	945537.00
	Tz	15.13	14.95	31.06	12.89	13.35	21.99
Mooring 2 - Vert (N)	Mean	829326.00	520718.00	578056.00	850785.00	520390.00	579671.00
	STD	21914.00	9897.00	11816.00	32117.00	17086.00	19816.00
	Max	908474.00	564111.00	620912.00	974951.00	588742.00	645153.00
	Min	768294.00	485981.00	534309.00	766644.00	468859.00	498194.00
	Tz	26.98	12.95	15.72	20.75	12.03	13.27
Mooring 3 - Vert (N)	Mean	729048.00	894091.00	233686.00	746552.00	931367.00	259044.00
	STD	18015.00	25359.00	14348.00	26535.00	37167.00	18646.00
	Max	792104.00	978254.00	272014.00	847973.00	1066234.00	307000.00
	Min	679312.00	826892.00	176485.00	674771.00	833135.00	187471.00
	Tz	27.38	38.42	23.60	20.78	29.43	16.55
Mooring 4 - Vert (N)	Mean	217877.00	511725.00	440209.00	232264.00	513703.00	438805.00
	STD	17932.00	14180.00	15708.00	27592.00	25504.00	27426.00
	Max	267115.00	561159.00	507468.00	308709.00	597526.00	548939.00

Figure D-3 Anchor Load Summary – Mooring Intact – Pilot Test

PROPRIETARY – DO NOT COPY OR DISCLOSE

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		25 yr Cyclone Storm Offset	25 yr Cyclone Storm Offset	25 yr Cyclone Storm Offset	25 yr Cyclone Storm Offset	25 yr Cyclone Storm Offset	25 yr Cyclone Storm Offset
MCF Mooring Tension		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Simulation time	sec	3699	3699	3699	3699	3699	mean wind
Directions							
Waves	deg	0.00	45.00	225.00	0.00	45.00	225.00
Wind	deg	0.00	45.00	225.00	0.00	45.00	225.00
Current	deg	0.00	45.00	225.00	0.00	45.00	225.00
SurGace Current Speed	Gt/sec	0.72	0.72	0.72	0.72	0.72	0.72
Wave (m)	Height	6.78	6.78	6.78	6.78	6.78	6.78
	Hs	4.30	4.30	4.30	4.30	4.30	4.30
	Tp	12.03	12.03	12.03	12.03	12.03	12.03
	STD	1.07	1.07	1.07	1.07	1.07	1.07
	Hs/STD	4.02	4.02	4.02	4.02	4.02	4.02
Wind Speed (1 Hr | 10 m)	kts	0.00	0.00	0.00	0.00	0.00	0.00
Mooring 1 - Hor-X (N)	Mean	56394.00	41629.00	1402614.00	62306.00	48637.00	1475541.00
	STD	103917.00	77374.00	13821.00	106055.00	83228.00	15920.00
	Max	517248.00	392431.00	1557231.00	575382.00	460727.00	1653944.00
	Min	16772.00	12081.00	1363967.00	22164.00	17536.00	1362666.00
	Tz	10.25	13.83	20.42	10.70	9.35	39.38
Mooring 2 - Hor-X (N)	Mean	-2182706.00	-2307408.00	-1637324.00	-2495863.00	-2731768.00	-2051635.00
	STD	426255.00	566817.00	320172.00	520645.00	695527.00	452844.00
	Max	-1060469.00	-753178.00	-729793.00	-1045782.00	-733981.00	-711835.00
	Min	-2524341.00	-2665375.00	-1845214.00	-2893151.00	-3158025.00	-2334764.00
	Tz	21.63	8.50	10.17	7.00	11.50	12.00
Mooring 3 - Hor-X (N)	Mean	-1069036.00	-1240950.00	-87451.00	-1089006.00	-1277817.00	-96758.00
	STD	5363.00	7776.00	112338.00	6746.00	9615.00	116182.00
	Max	-1035387.00	-1214891.00	-31260.00	-1016648.00	-1208220.00	-44195.00
	Min	-1127153.00	-1317953.00	-553280.00	-1166539.00	-1396637.00	-604001.00
	Tz	16.06	14.69	9.86	17.85	14.05	7.58
Mooring 4 - Hor-X (N)	Mean	1043353.00	1553303.00	2384704.00	1337402.00	1955352.00	2823497.00
	STD	0.00	293832.00	0.00	316525.00	422304.00	738476.00
	Max	1239201.00	1746433.00	2822356.00	1616542.00	2242352.00	3336267.00
	Min	422431.00	663513.00	714208.00	396617.00	601583.00	677071.00
	Tz	0.00	12.00	0.00	226.19	11.00	13.00
Mooring 1 - Hor-Y (N)	Mean	47448.00	33431.00	1188636.00	52192.00	39182.00	1247098.00
	STD	89006.00	64716.00	11607.00	90441.00	69774.00	13608.00
	Max	440502.00	326337.00	1319652.00	487964.00	384200.00	1399715.00
	Min	13747.00	9120.00	1153451.00	18139.00	13449.00	1148599.00
	Tz	10.93	14.14	20.50	13.78	9.35	39.50
Mooring 2 - Hor-Y (N)	Mean	1321472.00	1299251.00	2003294.00	1582215.00	1637538.00	2374484.00
	STD	168490.00	0.00	502873.00	251988.00	349539.00	615515.00
	Max	1481275.00	1455329.00	2329730.00	1792778.00	1857467.00	2764401.00
	Min	879024.00	615531.00	641138.00	870321.00	603814.00	620824.00
	Tz	16.79	0.00	11.50	11.38	18.25	15.00
Mooring 3 - Hor-Y (N)	Mean	-887272.00	-1043106.00	-70212.00	-906607.00	-1073723.00	-78163.00
	STD	4333.00	6630.00	94785.00	5536.00	8036.00	98133.00
	Max	-860129.00	-1023456.00	-24134.00	-846900.00	-1016099.00	-34675.00
	Min	-933277.00	-1107560.00	-462749.00	-969581.00	-1171081.00	-506395.00
	Tz	16.06	14.69	9.89	17.85	14.10	10.16
Mooring 4 - Hor-Y (N)	Mean	-1269942.00	-2010555.00	-1245989.00	-1543334.00	-2371527.00	-1591485.00
	STD	339522.00	508312.00	226222.00	424094.00	616224.00	339741.00
	Max	-365239.00	-587170.00	-581393.00	-343027.00	-526739.00	-557789.00
	Min	-1548862.00	-2339320.00	-1417972.00	-1901513.00	-2777082.00	-1836343.00
	Tz	7.50	10.00	13.17	16.36	9.50	9.50
Mooring 1 - Vert (N)	Mean	20235.00	13221.00	1015231.00	21251.00	15172.00	1081002.00
	STD	0.00	19565.00	11961.00	0.00	26274.00	13731.00
	Max	242698.00	129799.00	1147510.00	284695.00	186902.00	1237720.00
	Min	360.00	1535.00	981070.00	672.00	1396.00	983005.00
	Tz	0.00	15.17	20.58	0.00	15.00	31.60
Mooring 2 - Vert (N)	Mean	1627758.00	1696232.00	1654615.00	1935896.00	2102099.00	2069820.00
	STD	320155.00	0.00	421528.00	415221.00	561912.00	551719.00
	Max	1894968.00	1973746.00	1926857.00	2263922.00	2452011.00	2416983.00
	Min	787180.00	493951.00	493596.00	778795.00	476952.00	475060.00
	Tz	18.25	0.00	12.00	7.75	12.25	14.50
Mooring 3 - Vert (N)	Mean	724891.00	884589.00	23905.00	746613.00	922042.00	25817.00
	STD	4710.00	6978.00	0.00	5880.00	8556.00	0.00
	Max	775374.00	952454.00	260240.00	814892.00	1026023.00	302373.00
	Min	697376.00	865145.00	257.00	685208.00	862232.00	151.00
	Tz	13.95	14.19	0.00	18.20	16.39	0.00
Mooring 4 - Vert (N)	Mean	882081.00	1463506.00	1558406.00	1150102.00	1826360.00	1934088.00
	STD	0.00	375694.00	412520.00	349530.00	488171.00	530837.00
	Max	1105895.00	1705084.00	1856172.00	1449493.00	2148309.00	2299409.00

Figure D-4 Anchor Load Summary – Mooring Broken – Pilot Test

PROPRIETARY – DO NOT COPY OR DISCLOSE

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MCF Mooring Tension		100 yr Cyclone Storm Offset Case 1	100 yr Cyclone Storm Offset Case 2	100 yr Cyclone Storm Offset Case 3	100 yr Cyclone Storm Tension Case 4	100 yr Cyclone Storm Tension Case 5	100 yr Cyclone Storm Tension Case 6
Simulation time	sec	3699	3699	3699	3699	3699	3699
Directions							
Waves	deg	0.00	45.00	225.00	0.00	45.00	225.00
Wind	deg	0.00	45.00	225.00	0.00	45.00	225.00
Current	deg	0.00	45.00	225.00	0.00	45.00	225.00
SurGace Current Speed	Gt/sec	1.40	1.40	1.40	1.40	1.40	1.40
Wave (m)	Height	15.22	15.22	7.46	15.22	15.22	7.46
	Hs	10.20	10.20	5.00	10.20	10.20	5.00
	Tp	13.86	13.86	13.86	13.86	13.86	13.86
	STD	2.52	2.52	1.23	2.52	2.52	1.23
	Hs/STD	4.05	4.05	4.07	4.05	4.05	4.07
Wind Speed (1 Hr | 10 m)	kts	0.00	0.00	0.00	0.00	0.00	0.00
Mooring 1 - Hor-X (N)	Mean	217677.00	164331.00	1985357.00	264425.00	216950.00	2047177.00
	STD	46745.00	56471.00	86548.00	70138.00	63102.00	121143.00
	Max	410770.00	390064.00	2274759.00	641343.00	552884.00	2466552.00
	Min	84244.00	-20457.00	1727921.00	90659.00	46976.00	1681593.00
	Tz	14.37	11.13	30.34	13.29	10.70	22.66
Mooring 2 - Hor-X (N)	Mean	205750.00	137685.00	1702768.00	244694.00	182680.00	1754513.00
	STD	36327.00	48254.00	73574.00	58500.00	53417.00	102074.00
	Max	358617.00	323773.00	1950155.00	543443.00	458609.00	2111508.00
	Min	105044.00	-40980.00	1490742.00	104912.00	34721.00	1451727.00
	Tz	15.10	11.17	31.34	14.44	10.89	23.08
Mooring 3 - Hor-X (N)	Mean	-1387090.00	-618998.00	-743525.00	-1414353.00	-609471.00	-742335.00
	STD	80195.00	22087.00	10347.00	118549.00	41943.00	19018.00
	Max	-1153348.00	-541883.00	-708892.00	-1075394.00	-460600.00	-678151.00
	Min	-1669333.00	-693885.00	-779595.00	-1851109.00	-750483.00	-807864.00
	Tz	25.19	14.06	17.18	21.09	13.72	15.85
Mooring 4 - Hor-X (N)	Mean	-1769695.00	-945117.00	-736720.00	-1830296.00	-925194.00	-738662.00
	STD	109095.00	37446.00	14931.00	162951.00	63578.00	26486.00
	Max	-1453216.00	-820473.00	-690377.00	-1369594.00	-716283.00	-654842.00
	Min	-2149974.00	-1084266.00	-778860.00	-2432334.00	-1124822.00	-817767.00
	Tz	25.74	16.85	17.67	21.46	15.42	15.77
Mooring 5 - Hor-X (N)	Mean	-1707984.00	-2096303.00	-387556.00	-1767629.00	-2168632.00	-436106.00
	STD	100065.00	127278.00	31608.00	149870.00	186116.00	64363.00
	Max	-1411544.00	-1715774.00	-297977.00	-1341291.00	-1644615.00	-261045.00
	Min	-2044934.00	-2497152.00	-485995.00	-2320277.00	-2814774.00	-667981.00
	Tz	26.81	27.96	16.01	21.99	23.38	15.48
Mooring 6 - Hor-X (N)	Mean	-1342204.00	-1787486.00	-326306.00	-1376616.00	-1846890.00	-368015.00
	STD	73908.00	107969.00	25891.00	110112.00	156742.00	51566.00
	Max	-1121399.00	-1463397.00	-253517.00	-1062109.00	-1403029.00	-224756.00
	Min	-1590430.00	-2129047.00	-407078.00	-1782620.00	-2393529.00	-554224.00
	Tz	26.61	27.96	16.22	22.12	23.53	15.42
Mooring 7 - Hor-X (N)	Mean	240829.00	786327.00	602676.00	280590.00	788793.00	596910.00
	STD	42948.00	19701.00	12879.00	72103.00	36705.00	22801.00
	Max	418434.00	848391.00	649483.00	616569.00	910258.00	675479.00
	Min	134328.00	719814.00	561130.00	119995.00	671141.00	526892.00
	Tz	15.73	16.94	14.53	14.73	15.06	13.80
Mooring 8 - Hor-X (N)	Mean	254186.00	678163.00	894999.00	303569.00	683199.00	880225.00
	STD	53663.00	29610.00	19871.00	87811.00	51373.00	32883.00
	Max	473705.00	761875.00	968190.00	736020.00	814576.00	984937.00
	Min	114231.00	585778.00	823509.00	111448.00	499309.00	772341.00
	Tz	15.12	17.86	15.94	14.08	15.06	14.82

Figure D-5 Hor. X Anchor Load Summary – Mooring Intact – 100 Year Cyclone - Production

PROPRIETARY – DO NOT COPY OR DISCLOSE

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MCF Mooring Tension		100 yr Cyclone Storm Offset Case 1	100 yr Cyclone Storm Offset Case 2	100 yr Cyclone Storm Offset Case 3	100 yr Cyclone Storm Tension Case 4	100 yr Cyclone Storm Tension Case 5	100 yr Cyclone Storm Tension Case 6
Simulation time	sec	3699	3699	3699	3699	3699	3699
Directions							
Waves	deg	0.00	45.00	225.00	0.00	45.00	225.00
Wind	deg	0.00	45.00	225.00	0.00	45.00	225.00
Current	deg	0.00	45.00	225.00	0.00	45.00	225.00
SurGace Current Speed	Gt/sec	1.40	1.40	1.40	1.40	1.40	1.40
Wave (m)	Height	15.22	15.22	7.46	15.22	15.22	7.46
	Hs	10.20	10.20	5.00	10.20	10.20	5.00
	Tp	13.86	13.86	13.86	13.86	13.86	13.86
	STD	2.52	2.52	1.23	2.52	2.52	1.23
	Hs/STD	4.05	4.05	4.07	4.05	4.05	4.07
Wind Speed (1 Hr | 10 m)	kts	0.00	0.00	0.00	0.00	0.00	0.00
Mooring 1 - Hor-Y (N)	Mean	190646.00	136583.00	1672811.00	228233.00	180799.00	1722096.00
	STD	40794.00	46993.00	73553.00	60498.00	52662.00	102671.00
	Max	360445.00	323429.00	1923674.00	554374.00	460966.00	2082543.00
	Min	74188.00	-16463.00	1459798.00	78278.00	39094.00	1411320.00
	Tz	14.37	11.30	29.71	13.24	10.79	21.99
Mooring 2 - Hor-Y (N)	Mean	257986.00	164973.00	2024083.00	301539.00	218294.00	2087743.00
	STD	45318.00	57818.00	87681.00	72040.00	63878.00	122213.00
	Max	450350.00	389277.00	2320846.00	670111.00	547724.00	2519335.00
	Min	131795.00	-50461.00	1771196.00	128658.00	41464.00	1717504.00
	Tz	15.03	11.17	30.39	14.22	10.86	22.12
Mooring 3 - Hor-Y (N)	Mean	1591553.00	696931.00	916788.00	1645739.00	700807.00	903969.00
	STD	88439.00	24651.00	12596.00	135948.00	48017.00	22670.00
	Max	1901484.00	780332.00	960656.00	2145370.00	862754.00	981291.00
	Min	1333867.00	611733.00	874428.00	1256651.00	531290.00	826842.00
	Tz	23.91	14.45	17.23	20.67	13.70	16.05
Mooring 4 - Hor-Y (N)	Mean	1436611.00	748826.00	640430.00	1504213.00	749173.00	634087.00
	STD	85920.00	27577.00	12085.00	132521.00	49895.00	22042.00
	Max	1734635.00	851857.00	676147.00	1988710.00	903855.00	700357.00
	Min	1187486.00	657036.00	601507.00	1127212.00	585614.00	564341.00
	Tz	24.07	16.38	16.88	21.02	15.16	15.86
Mooring 5 - Hor-Y (N)	Mean	-1399090.00	-1765270.00	-323896.00	-1461057.00	-1823349.00	-364899.00
	STD	79472.00	105453.00	26498.00	122156.00	154367.00	53868.00
	Max	-1164134.00	-1443652.00	-248514.00	-1111446.00	-1385410.00	-218405.00
	Min	-1665455.00	-2092559.00	-406743.00	-1910178.00	-2352926.00	-558223.00
	Tz	26.21	29.48	15.94	21.85	23.84	15.48
Mooring 6 - Hor-Y (N)	Mean	-1553440.00	-2120812.00	-389528.00	-1610607.00	-2194621.00	-439017.00
	STD	81981.00	125056.00	30951.00	126196.00	183163.00	61509.00
	Max	-1308908.00	-1737591.00	-302330.00	-1245790.00	-1671906.00	-268150.00
	Min	-1828047.00	-2506968.00	-487164.00	-2074058.00	-2827530.00	-660627.00
	Tz	25.65	29.34	16.01	21.72	23.53	15.42
Mooring 7 - Hor-Y (N)	Mean	-302792.00	-1003288.00	-690186.00	-346451.00	-981044.00	-693753.00
	STD	53770.00	27475.00	14216.00	89043.00	46841.00	25716.00
	Max	-168952.00	-910844.00	-645916.00	-147788.00	-831377.00	-615116.00
	Min	-527501.00	-1086244.00	-742220.00	-763309.00	-1142894.00	-783366.00
	Tz	15.49	17.02	15.04	14.58	15.10	14.08
Mooring 8 - Hor-Y (N)	Mean	-223333.00	-609225.00	-722254.00	-262649.00	-598785.00	-720836.00
	STD	47025.00	24087.00	15172.00	75978.00	43098.00	26135.00
	Max	-100769.00	-532832.00	-667976.00	-96013.00	-442373.00	-637103.00
	Min	-417089.00	-678920.00	-777103.00	-637512.00	-713002.00	-804814.00
	Tz	15.02	17.00	15.89	14.02	14.67	14.80

Figure D-6 Hor. Y Anchor Load Summary – Mooring Intact – 100 Year Cyclone - Production

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		100 yr Cyclone Storm Offset	100 yr Cyclone Storm Offset	100 yr Cyclone Storm Offset	100 yr Cyclone Storm Tension	100 yr Cyclone Storm Tension	100 yr Cyclone Storm Tension
MCF Mooring Tension		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Simulation time	sec	3699	3699	3699	3699	3699	3699
Directions							
Waves	deg	0.00	45.00	225.00	0.00	45.00	225.00
Wind	deg	0.00	45.00	225.00	0.00	45.00	225.00
Current	deg	0.00	45.00	225.00	0.00	45.00	225.00
SurGace Current Speed	Gt/sec	1.40	1.40	1.40	1.40	1.40	1.40
Wave (m)	Height	15.22	15.22	7.46	15.22	15.22	7.46
	Hs	10.20	10.20	5.00	10.20	10.20	5.00
	Tp	13.86	13.86	13.86	13.86	13.86	13.86
	STD	2.52	2.52	1.23	2.52	2.52	1.23
	Hs/STD	4.05	4.05	4.07	4.05	4.05	4.07
Wind Speed (1 Hr | 10 m)	kts	0.00	0.00	0.00	0.00	0.00	0.00
Mooring 1 - Vert (N)	Mean	16063.00	14420.00	1508386.00	37117.00	19003.00	1574172.00
	STD	12536.00	3759.00	74440.00	36797.00	18789.00	106139.00
	Max	129896.00	85624.00	1759309.00	308778.00	226659.00	1943885.00
	Min	-116.00	-701.00	1290536.00	-17.00	-53.00	1255043.00
	Tz	6.13	5.64	29.96	15.32	12.60	21.74
Mooring 2 - Vert (N)	Mean	20727.00	14606.00	1486358.00	49388.00	18173.00	1552192.00
	STD	17588.00	3329.00	72700.00	39644.00	16571.00	103140.00
	Max	127481.00	72583.00	1731886.00	291042.00	211017.00	1915089.00
	Min	-30.00	-644.00	1275683.00	-6.00	-99.00	1241532.00
	Tz	16.95	6.07	30.21	15.21	9.16	21.74
Mooring 3 - Vert (N)	Mean	1222417.00	420129.00	589483.00	1270901.00	417338.00	582597.00
	STD	79595.00	19818.00	10266.00	122757.00	36950.00	19053.00
	Max	1505432.00	487654.00	622967.00	1724331.00	542548.00	645028.00
	Min	991342.00	353562.00	555292.00	926629.00	289351.00	518610.00
	Tz	24.57	14.33	17.78	21.03	14.15	16.56
Mooring 4 - Vert (N)	Mean	1435265.00	662512.00	493548.00	1512347.00	652082.00	491310.00
	STD	98645.00	31703.00	12930.00	152484.00	53935.00	23246.00
	Max	1784811.00	782773.00	533117.00	2078821.00	822512.00	560468.00
	Min	1150996.00	559273.00	452260.00	1085790.00	481001.00	418708.00
	Tz	25.62	17.22	17.89	21.39	15.80	16.49
Mooring 5 - Vert (N)	Mean	1287233.00	1646174.00	113866.00	1356221.00	1727581.00	157221.00
	STD	85385.00	110630.00	22596.00	131473.00	165675.00	43945.00
	Max	1573080.00	1995852.00	183700.00	1847303.00	2307969.00	312081.00
	Min	1031989.00	1314578.00	51579.00	986428.00	1267042.00	35996.00
	Tz	27.91	30.12	17.65	22.69	23.74	15.62
Mooring 6 - Vert (N)	Mean	1152249.00	1628708.00	108283.00	1204514.00	1709845.00	151505.00
	STD	72225.00	108330.00	21581.00	110877.00	161747.00	41302.00
	Max	1394365.00	1969045.00	174425.00	1614117.00	2278371.00	298267.00
	Min	933372.00	1302401.00	48913.00	888852.00	1256648.00	34185.00
	Tz	27.48	30.90	17.83	22.83	23.74	15.62
Mooring 7 - Vert (N)	Mean	61783.00	673973.00	427763.00	101375.00	664049.00	426573.00
	STD	34057.00	21743.00	12162.00	56707.00	39133.00	21036.00
	Max	191463.00	742539.00	472169.00	378956.00	796048.00	499936.00
	Min	-153.00	598959.00	389418.00	-602.00	540168.00	364313.00
	Tz	16.02	18.27	15.20	14.65	15.50	14.37
Mooring 8 - Vert (N)	Mean	27081.00	395327.00	554185.00	61070.00	392707.00	546301.00
	STD	24012.00	23936.00	15408.00	50762.00	40395.00	25836.00
	Max	167500.00	464966.00	611808.00	355210.00	496926.00	629945.00
	Min	-17.00	323431.00	501101.00	-42.00	254267.00	465816.00
	Tz	15.97	19.16	16.59	14.84	16.33	15.26

Figure D-7 Vertical Anchor Load Summary – Mooring Intact – 100 Year Cyclone - Production

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EXCEPT UNDER TERMS OF SUBCONTRACT AGREEMENT DMP15722JHA001 Dated 12 Jan. 2010

MCF Mooring Tension		100 yr Cyclone Storm Offset Case 1	100 yr Cyclone Storm Offset Case 2	100 yr Cyclone Storm Offset Case 3	100 yr Cyclone Storm Tension Case 4	100 yr Cyclone Storm Tension Case 5	100 yr Cyclone Storm Tension Case 6
Simulation time	sec	3699	3699	3699	3699	3699	mean wind
Directions							
Waves	deg	0.00	45.00	225.00	0.00	45.00	225.00
Wind	deg	0.00	45.00	225.00	0.00	45.00	225.00
Current	deg	0.00	45.00	225.00	0.00	45.00	225.00
SurGace Current Speed	Gt/sec	1.40	1.40	1.40	1.40	1.40	1.40
Wave (m)	Height	15.22	15.22	7.46	15.22	15.22	7.46
	Hs	10.20	10.20	5.00	10.20	10.20	5.00
	Tp	13.86	13.86	13.86	13.86	13.86	13.86
	STD	2.52	2.52	1.23	2.52	2.52	1.23
	Hs/STD	4.05	4.05	4.07	4.05	4.05	4.07
Wind Speed (1 Hr | 10 m)	kts	0.00	0.00	0.00	0.00	0.00	0.00
Mooring 1 - Hor-X (N)	Mean	114348.00	89285.00	2001467.00	158820.00	128246.00	2077766.00
	STD	55873.00	43935.00	22640.00	63901.00	64692.00	32806.00
	Max	340302.00	330228.00	2086599.00	472440.00	432323.00	2216999.00
	Min	-19747.00	-71730.00	1751674.00	-79304.00	-85578.00	1699669.00
	Tz	11.93	8.22	44.25	10.27	9.55	24.25
Mooring 2 - Hor-X (N)	Mean	102594.00	74890.00	2962846.00	142176.00	108034.00	3100939.00
	STD	46737.00	36080.00	352023.00	50966.00	54718.00	380157.00
	Max	256076.00	287788.00	3404597.00	427125.00	373996.00	3697712.00
	Min	-24430.00	-50057.00	2786539.00	5060.00	-81876.00	2814602.00
	Tz	11.98	8.22	51.08	11.34	9.35	34.71
Mooring 3 - Hor-X (N)	Mean	-1417710.00	-652304.00	-761875.00	-1423085.00	-621640.00	-753305.00
	STD	84303.00	26293.00	11822.00	119817.00	44106.00	18609.00
	Max	-1179953.00	-543947.00	-712091.00	-1081286.00	-461653.00	-686721.00
	Min	-1697753.00	-737558.00	-803511.00	-1863246.00	-759650.00	-818121.00
	Tz	26.88	15.04	18.05	21.09	13.82	16.34
Mooring 4 - Hor-X (N)	Mean	-2041912.00	-1272155.00	-634301.00	-2100532.00	-1224035.00	-637988.00
	STD	139366.00	99485.00	30896.00	185939.00	106173.00	37154.00
	Max	-1716663.00	-1141884.00	-586307.00	-1598536.00	-1019194.00	-553675.00
	Min	-2456492.00	-1475671.00	-669715.00	-2743178.00	-1505033.00	-710903.00
	Tz	29.27	22.98	20.28	23.20	17.18	17.01
Mooring 5 - Hor-X (N)	Mean	-1673685.00	-2025233.00	-247387.00	-1783113.00	-2139432.00	-303860.00
	STD	22619.00	30082.00	43344.00	33795.00	37501.00	53295.00
	Max	-1486921.00	-1824864.00	-169645.00	-1360954.00	-1690729.00	-201688.00
	Min	-1948266.00	-2395140.00	-478867.00	-2093991.00	-2559653.00	-633152.00
	Tz	17.75	18.07	15.76	19.83	17.90	15.58
Mooring 6 - Hor-X (N)	Mean	-2391211.00	-3164825.00	-208719.00	-2505732.00	-3315782.00	-257177.00
	STD	296221.00	395422.00	36488.00	331348.00	436923.00	43917.00
	Max	-2150402.00	-2834913.00	-137148.00	-2123822.00	-2798897.00	-170509.00
	Min	-2791943.00	-3718624.00	-275705.00	-3143175.00	-4082596.00	-450166.00
	Tz	66.32	65.55	15.61	40.72	42.65	15.32
Mooring 7 - Hor-X (N)	Mean	254026.00	873669.00	625271.00	289685.00	857702.00	613137.00
	STD	43962.00	31893.00	14978.00	74203.00	39994.00	24106.00
	Max	433118.00	946272.00	677340.00	634843.00	977256.00	698377.00
	Min	141716.00	800974.00	564124.00	118545.00	700356.00	531207.00
	Tz	15.79	21.93	15.31	14.32	17.08	14.17
Mooring 8 - Hor-X (N)	Mean	224863.00	525636.00	1128800.00	273910.00	530551.00	1106690.00
	STD	49188.00	47255.00	66155.00	75422.00	60471.00	69343.00
	Max	415351.00	595538.00	1241541.00	649727.00	660361.00	1260391.00
	Min	91418.00	438195.00	1064680.00	104615.00	359752.00	1003430.00
	Tz	14.70	19.11	23.75	14.03	14.94	17.68

Figure D-8 Hor. X Anchor Load Summary – Mooring Broken – 100 Year Cyclone - Production

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		100 yr Cyclone Storm Offset	100 yr Cyclone Storm Offset	100 yr Cyclone Storm Offset	100 yr Cyclone Storm Tension	100 yr Cyclone Storm Tension	100 yr Cyclone Storm Tension
MCF Mooring Tension		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Simulation time	sec	3699	3699	3699	3699	3699	mean wind
Directions							
Waves	deg	0.00	45.00	225.00	0.00	45.00	225.00
Wind	deg	0.00	45.00	225.00	0.00	45.00	225.00
Current	deg	0.00	45.00	225.00	0.00	45.00	225.00
SurGace Current Speed	Gt/sec	1.40	1.40	1.40	1.40	1.40	1.40
Wave (m)	Height	15.22	15.22	7.46	15.22	15.22	7.46
	Hs	10.20	10.20	5.00	10.20	10.20	5.00
	Tp	13.86	13.86	13.86	13.86	13.86	13.86
	STD	2.52	2.52	1.23	2.52	2.52	1.23
	Hs/STD	4.05	4.05	4.07	4.05	4.05	4.07
Wind Speed (1 Hr | 10 m)	kts	0.00	0.00	0.00	0.00	0.00	0.00
Mooring 1 - Hor-Y (N)	Mean	100621.00	74007.00	1685315.00	137526.00	106701.00	1745660.00
	STD	49231.00	36452.00	19092.00	55193.00	53802.00	27472.00
	Max	300602.00	285196.00	1762248.00	407053.00	359974.00	1867930.00
	Min	-18642.00	-62152.00	1474711.00	-71003.00	-71816.00	1427492.00
	Tz	11.89	8.15	35.40	10.16	9.55	21.56
Mooring 2 - Hor-Y (N)	Mean	130647.00	90706.00	3500425.00	176836.00	129925.00	3675810.00
	STD	59151.00	43421.00	412730.00	62908.00	65638.00	448931.00
	Max	326327.00	344529.00	4033261.00	527399.00	448031.00	4390812.00
	Min	-31471.00	-59519.00	3304012.00	6176.00	-100556.00	3340053.00
	Tz	12.01	8.11	46.77	11.27	9.24	33.31
Mooring 3 - Hor-Y (N)	Mean	1559505.00	695069.00	970691.00	1615808.00	692611.00	934532.00
	STD	88236.00	25849.00	20486.00	133788.00	48856.00	23929.00
	Max	1849495.00	787418.00	1030305.00	2104687.00	868952.00	1016133.00
	Min	1316631.00	603507.00	928949.00	1253413.00	524683.00	843270.00
	Tz	24.60	14.07	20.17	21.03	13.67	16.96
Mooring 4 - Hor-Y (N)	Mean	1587330.00	952371.00	569843.00	1683727.00	960227.00	558202.00
	STD	97112.00	62833.00	22455.00	143403.00	77072.00	29965.00
	Max	1887910.00	1087643.00	600950.00	2185829.00	1170772.00	623082.00
	Min	1346095.00	859369.00	530086.00	1252036.00	803043.00	487745.00
	Tz	28.35	20.85	18.42	23.11	17.10	16.45
Mooring 5 - Hor-Y (N)	Mean	-1368245.00	-1702108.00	-206587.00	-1471975.00	-1796539.00	-254170.00
	STD	18335.00	25253.00	36267.00	27439.00	30871.00	44634.00
	Max	-1221068.00	-1543963.00	-141551.00	-1127596.00	-1427274.00	-168235.00
	Min	-1584134.00	-1999839.00	-401043.00	-1729768.00	-2135791.00	-529179.00
	Tz	16.64	19.17	15.76	19.83	18.39	15.52
Mooring 6 - Hor-Y (N)	Mean	-2755140.00	-3730438.00	-250286.00	-2924602.00	-3924373.00	-307650.00
	STD	337506.00	461505.00	43358.00	384073.00	513893.00	52340.00
	Max	-2488934.00	-3365656.00	-164239.00	-2485666.00	-3324023.00	-203739.00
	Min	-3196119.00	-4367175.00	-330677.00	-3653051.00	-4825240.00	-536678.00
	Tz	63.78	63.27	15.61	39.30	41.60	15.32
Mooring 7 - Hor-Y (N)	Mean	-336980.00	-1192309.00	-689037.00	-368747.00	-1107963.00	-697111.00
	STD	58547.00	61939.00	15006.00	94633.00	59181.00	26353.00
	Max	-182605.00	-1083057.00	-641201.00	-150535.00	-934855.00	-611278.00
	Min	-578098.00	-1316480.00	-752759.00	-814509.00	-1268867.00	-795012.00
	Tz	15.88	24.22	14.86	14.08	17.53	14.03
Mooring 8 - Hor-Y (N)	Mean	-208150.00	-503448.00	-877121.00	-244174.00	-482544.00	-887332.00
	STD	45002.00	35356.00	44238.00	67007.00	50347.00	51899.00
	Max	-85461.00	-428540.00	-825192.00	-93387.00	-329973.00	-805317.00
	Min	-381339.00	-567709.00	-955956.00	-583709.00	-600568.00	-1004360.00
	Tz	14.62	18.12	22.20	13.97	14.68	17.35

Figure D-9 Hor. Y Anchor Load Summary – Mooring Broken – 100 Year Cyclone - Production

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MCF Mooring Tension		100 yr Cyclone Storm Offset Case 1	100 yr Cyclone Storm Offset Case 2	100 yr Cyclone Storm Offset Case 3	100 yr Cyclone Storm Tension Case 4	100 yr Cyclone Storm Tension Case 5	100 yr Cyclone Storm Tension Case 6
Simulation time	sec	3699	3699	3699	3699	3699	mean wind
Directions							
Waves	deg	0.00	45.00	225.00	0.00	45.00	225.00
Wind	deg	0.00	45.00	225.00	0.00	45.00	225.00
Current	deg	0.00	45.00	225.00	0.00	45.00	225.00
SurGace Current Speed	Gt/sec	1.40	1.40	1.40	1.40	1.40	1.40
Wave (m)	Height	15.22	15.22	7.46	15.22	15.22	7.46
	Hs	10.20	10.20	5.00	10.20	10.20	5.00
	Tp	13.86	13.86	13.86	13.86	13.86	13.86
	STD	2.52	2.52	1.23	2.52	2.52	1.23
	Hs/STD	4.05	4.05	4.07	4.05	4.05	4.07
Wind Speed (1 Hr | 10 m)	kts	0.00	0.00	0.00	0.00	0.00	0.00
Mooring 1 - Vert (N)	Mean	13374.00	12268.00	1513989.00	15773.00	13965.00	1587692.00
	STD	3273.00	2031.00	18383.00	10789.00	5247.00	26970.00
	Max	61488.00	20766.00	1601261.00	179609.00	135608.00	1726200.00
	Min	57.00	134.00	1305548.00	7.00	20.00	1271092.00
	Tz	9.61	7.92	29.42	5.91	6.13	24.25
Mooring 2 - Vert (N)	Mean	13981.00	12315.00	2681136.00	16981.00	13975.00	2870233.00
	STD	4646.00	2007.00	333494.00	12910.00	4828.00	372393.00
	Max	99360.00	20946.00	3111357.00	231169.00	137194.00	3463082.00
	Min	-2702.00	281.00	2517746.00	-612.00	-2493.00	2590542.00
	Tz	11.31	8.06	44.87	8.62	6.41	32.99
Mooring 3 - Vert (N)	Mean	1219891.00	434543.00	626504.00	1259250.00	418567.00	604008.00
	STD	80975.00	21817.00	15244.00	122085.00	38036.00	19595.00
	Max	1490729.00	509955.00	672346.00	1713017.00	552196.00	667869.00
	Min	995157.00	354035.00	593465.00	928111.00	283363.00	532511.00
	Tz	24.99	15.11	20.02	21.16	13.94	17.61
Mooring 4 - Vert (N)	Mean	1653555.00	941487.00	403101.00	1746954.00	920900.00	398722.00
	STD	120023.00	84472.00	27117.00	170210.00	94452.00	32872.00
	Max	2012438.00	1114059.00	434649.00	2343962.00	1177870.00	453984.00
	Min	1368773.00	831215.00	361452.00	1214403.00	737064.00	325114.00
	Tz	30.78	23.78	20.66	23.56	17.90	17.35
Mooring 5 - Vert (N)	Mean	1251506.00	1575757.00	19241.00	1353463.00	1686030.00	39743.00
	STD	19844.00	27178.00	26078.00	28818.00	33434.00	39169.00
	Max	1481094.00	1890064.00	179978.00	1649638.00	2073048.00	294962.00
	Min	1100006.00	1416340.00	4.00	1005178.00	1311805.00	31.00
	Tz	17.69	20.07	679.25	19.50	16.50	16.73
Mooring 6 - Vert (N)	Mean	2202667.00	2995782.00	19576.00	2372639.00	3222111.00	37118.00
	STD	294747.00	391027.00	24509.00	341096.00	448903.00	37552.00
	Max	2585884.00	3534173.00	NaN	3018675.00	4007351.00	116067.00
	Min	1970766.00	2678957.00	NaN	1987738.00	2691274.00	-41.00
	Tz	67.65	62.20	1358.00	39.73	39.64	16.57
Mooring 7 - Vert (N)	Mean	85697.00	814230.00	437555.00	117306.00	763221.00	435738.00
	STD	37561.00	46528.00	13138.00	59599.00	47985.00	21934.00
	Max	213890.00	908664.00	489494.00	392467.00	899913.00	517019.00
	Min	-2109.00	727005.00	393420.00	-3741.00	623308.00	363457.00
	Tz	16.88	24.76	15.49	14.54	17.92	14.63
Mooring 8 - Vert (N)	Mean	17880.00	273419.00	738730.00	42206.00	265411.00	733306.00
	STD	15295.00	38191.00	52030.00	40865.00	48090.00	56881.00
	Max	126676.00	331354.00	828171.00	302565.00	353905.00	860608.00
	Min	-39.00	203267.00	688199.00	-35.00	142854.00	652305.00
	Tz	14.37	19.88	24.66	15.20	15.61	18.45

Figure D-10 Vertical Anchor Load Summary – Mooring Broken – 100 Year Cyclone - Production

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MCF Mooring Tension		10 yr Swell Storm Offset Case 7	10 yr Swell Storm Offset Case 8	10 yr Swell Storm Offset Case 9	10 yr Swell Storm Tension Case 10	10 yr Swell Storm Tension Case 11	10 yr Swell Storm Tension Case 12
Simulation time	sec	3699	3699	3699	3699	3699	3699
Directions							
Waves	deg	0.00	45.00	225.00	0.00	45.00	225.00
Wind	deg	0.00	45.00	225.00	0.00	45.00	225.00
Current	deg	0.00	45.00	225.00	0.00	45.00	225.00
SurGace Current Speed	Gt/sec	0.48	0.48	0.48	0.48	0.48	0.48
Wave (m)	Height	5.29	5.29	5.29	5.29	5.29	5.29
	Hs	3.80	3.80	3.80	3.80	3.80	3.80
	Tp	18.01	18.01	18.01	18.01	18.01	18.01
	STD	0.94	0.94	0.94	0.94	0.94	0.94
	Hs/STD	4.04	4.04	4.04	4.04	4.04	4.04
Wind Speed (1 Hr | 10 m)	kts	0.00	0.00	0.00	0.00	0.00	0.00
Mooring 1 - Hor-X (N)	Mean	642459.00	606906.00	1001370.00	645465.00	611266.00	1011810.00
	STD	38722.00	40601.00	52870.00	59332.00	61790.00	97831.00
	Max	735672.00	708095.00	1209293.00	812543.00	784250.00	1377211.00
	Min	507274.00	469223.00	845891.00	446980.00	399447.00	741616.00
	Tz	16.91	16.23	17.09	16.23	15.35	16.68
Mooring 2 - Hor-X (N)	Mean	562558.00	513889.00	852185.00	564098.00	517671.00	860494.00
	STD	28705.00	32892.00	43363.00	44736.00	50107.00	80398.00
	Max	633120.00	595191.00	1021879.00	691260.00	656539.00	1159149.00
	Min	462740.00	401057.00	723369.00	415049.00	343765.00	635611.00
	Tz	17.22	16.23	16.86	16.38	15.23	16.68
Mooring 3 - Hor-X (N)	Mean	-771881.00	-675516.00	-691939.00	-776902.00	-675590.00	-693314.00
	STD	29014.00	15032.00	18630.00	51447.00	25192.00	31572.00
	Max	-684507.00	-625908.00	-642011.00	-626380.00	-591372.00	-608134.00
	Min	-883291.00	-727329.00	-740378.00	-966665.00	-762817.00	-780990.00
	Tz	17.23	17.83	19.24	16.53	17.57	18.75
Mooring 4 - Hor-X (N)	Mean	-913926.00	-809777.00	-779138.00	-922564.00	-811568.00	-780487.00
	STD	39026.00	22223.00	24349.00	69423.00	38393.00	41009.00
	Max	-797960.00	-737916.00	-709070.00	-723651.00	-688257.00	-657665.00
	Min	-1063483.00	-892143.00	-844988.00	-1180947.00	-951340.00	-893761.00
	Tz	17.06	17.74	18.59	16.53	16.84	18.04
Mooring 5 - Hor-X (N)	Mean	-901637.00	-927790.00	-685288.00	-909256.00	-937908.00	-688304.00
	STD	37176.00	40258.00	39753.00	73236.00	78526.00	94747.00
	Max	-796055.00	-812939.00	-558670.00	-711462.00	-720042.00	-426297.00
	Min	-1044930.00	-1080534.00	-788657.00	-1161219.00	-1206539.00	-971241.00
	Tz	17.31	16.91	17.06	16.53	16.39	16.68
Mooring 6 - Hor-X (N)	Mean	-750878.00	-786273.00	-579512.00	-755667.00	-794322.00	-582415.00
	STD	27420.00	33029.00	31585.00	54280.00	64318.00	74547.00
	Max	-671325.00	-691440.00	-479449.00	-607454.00	-614089.00	-372846.00
	Min	-856371.00	-910980.00	-662380.00	-943999.00	-1014236.00	-802849.00
	Tz	17.48	17.00	17.06	16.46	16.39	16.53
Mooring 7 - Hor-X (N)	Mean	570629.00	680804.00	658391.00	572961.00	683418.00	658352.00
	STD	28138.00	21291.00	16691.00	44702.00	37596.00	26349.00
	Max	641238.00	736807.00	714220.00	695307.00	782412.00	748940.00
	Min	472753.00	621955.00	604307.00	425241.00	577141.00	571809.00
	Tz	17.06	19.15	18.01	16.38	18.75	17.34
Mooring 8 - Hor-X (N)	Mean	670228.00	793425.00	829539.00	673935.00	794937.00	830188.00
	STD	38195.00	26700.00	24145.00	59603.00	46153.00	39856.00
	Max	762870.00	867838.00	917940.00	831360.00	926086.00	976260.00
	Min	534652.00	718229.00	752734.00	473213.00	663721.00	706106.00
	Tz	16.98	18.61	17.93	16.02	18.42	16.80

Figure D-11 Hor. X Anchor Load Summary – Mooring Intact – 10 Year Swell - Production

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		10 yr Swell Storm Offset	10 yr Swell Storm Offset	10 yr Swell Storm Offset	10 yr Swell Storm Tension	10 yr Swell Storm Tension	10 yr Swell Storm Tension
MCF Mooring Tension		Case 7	Case 8	Case 9	Case 10	Case 11	Case 12
Simulation time	sec	3699	3699	3699	3699	3699	3699
Directions							
Waves	deg	0.00	45.00	225.00	0.00	45.00	225.00
Wind	deg	0.00	45.00	225.00	0.00	45.00	225.00
Current	deg	0.00	45.00	225.00	0.00	45.00	225.00
SurGace Current Speed	Gt/sec	0.48	0.48	0.48	0.48	0.48	0.48
Wave (m)	Height	5.29	5.29	5.29	5.29	5.29	5.29
	Hs	3.80	3.80	3.80	3.80	3.80	3.80
	Tp	18.01	18.01	18.01	18.01	18.01	18.01
	STD	0.94	0.94	0.94	0.94	0.94	0.94
	Hs/STD	4.04	4.04	4.04	4.04	4.04	4.04
Wind Speed (1 Hr | 10 m)	kts	0.00	0.00	0.00	0.00	0.00	0.00
Mooring 1 - Hor-Y (N)	Mean	543138.00	508578.00	840935.00	544940.00	512333.00	849504.00
	STD	32823.00	34586.00	44307.00	50147.00	52215.00	81996.00
	Max	623305.00	594566.00	1014500.00	687204.00	657875.00	1155625.00
	Min	429254.00	390348.00	712225.00	378221.00	333078.00	623586.00
	Tz	16.91	16.16	17.17	16.30	15.35	16.67
Mooring 2 - Hor-Y (N)	Mean	676351.00	612913.00	1014748.00	677078.00	617315.00	1024823.00
	STD	34656.00	39934.00	51794.00	53777.00	60283.00	95832.00
	Max	762681.00	711705.00	1216286.00	831005.00	784371.00	1379921.00
	Min	556851.00	475595.00	862715.00	498870.00	408501.00	757422.00
	Tz	17.47	16.23	17.01	16.31	15.23	16.67
Mooring 3 - Hor-Y (N)	Mean	913470.00	797429.00	832497.00	920614.00	799024.00	832636.00
	STD	34275.00	17635.00	21942.00	60741.00	29370.00	37464.00
	Max	1042810.00	855975.00	891832.00	1143004.00	898619.00	938127.00
	Min	810318.00	739199.00	774958.00	742284.00	700673.00	733751.00
	Tz	17.24	18.11	19.15	16.59	17.59	18.76
Mooring 4 - Hor-Y (N)	Mean	762313.00	672912.00	660285.00	770369.00	675639.00	660267.00
	STD	32620.00	18468.00	20127.00	57899.00	31671.00	34173.00
	Max	885335.00	739390.00	715508.00	984250.00	789396.00	755555.00
	Min	665755.00	612647.00	604074.00	604170.00	573901.00	559331.00
	Tz	17.11	18.02	18.61	16.66	16.95	18.13
Mooring 5 - Hor-Y (N)	Mean	-752682.00	-779068.00	-574460.00	-759512.00	-787466.00	-577032.00
	STD	30643.00	33414.00	33427.00	60689.00	65819.00	79381.00
	Max	-664607.00	-682851.00	-468289.00	-594743.00	-604085.00	-357748.00
	Min	-871129.00	-905762.00	-661260.00	-969448.00	-1012348.00	-813660.00
	Tz	17.39	16.91	17.06	16.53	16.32	16.68
Mooring 6 - Hor-Y (N)	Mean	-889333.00	-936406.00	-690990.00	-895732.00	-946059.00	-694425.00
	STD	31994.00	38733.00	37644.00	63758.00	76244.00	88755.00
	Max	-795323.00	-823515.00	-572053.00	-720386.00	-730975.00	-445067.00
	Min	-1012931.00	-1082606.00	-789911.00	-1118176.00	-1206381.00	-957343.00
	Tz	17.23	17.00	17.06	16.53	16.39	16.45
Mooring 7 - Hor-Y (N)	Mean	-686090.00	-820259.00	-776711.00	-687782.00	-821508.00	-778576.00
	STD	33878.00	25564.00	19972.00	53640.00	45068.00	31299.00
	Max	-569044.00	-750355.00	-710466.00	-511401.00	-695380.00	-675145.00
	Min	-772708.00	-890265.00	-841852.00	-835607.00	-942609.00	-883864.00
	Tz	17.05	19.14	18.19	16.30	18.75	17.58
Mooring 8 - Hor-Y (N)	Mean	-566619.00	-673146.00	-689101.00	-569016.00	-672936.00	-691269.00
	STD	32282.00	22640.00	20520.00	50290.00	38986.00	33556.00
	Max	-452468.00	-610867.00	-622663.00	-400421.00	-563955.00	-586459.00
	Min	-646379.00	-735987.00	-761781.00	-703279.00	-783272.00	-811335.00
	Tz	16.67	18.59	17.83	15.95	18.41	17.08

Figure D-12 Hor. Y Anchor Load Summary – Mooring Intact – 10 Year Swell - Production

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		10 yr Swell Storm Offset	10 yr Swell Storm Offset	10 yr Swell Storm Offset	10 yr Swell Storm Tension	10 yr Swell Storm Tension	10 yr Swell Storm Tension
MCF Mooring Tension		Case 7	Case 8	Case 9	Case 10	Case 11	Case 12
Simulation time	sec	3699	3699	3699	3699	3699	3699
Directions							
Waves	deg	0.00	45.00	225.00	0.00	45.00	225.00
Wind	deg	0.00	45.00	225.00	0.00	45.00	225.00
Current	deg	0.00	45.00	225.00	0.00	45.00	225.00
SurGace Current Speed	Gt/sec	0.48	0.48	0.48	0.48	0.48	0.48
Wave (m)	Height	5.29	5.29	5.29	5.29	5.29	5.29
	Hs	3.80	3.80	3.80	3.80	3.80	3.80
	Tp	18.01	18.01	18.01	18.01	18.01	18.01
	STD	0.94	0.94	0.94	0.94	0.94	0.94
	Hs/STD	4.04	4.04	4.04	4.04	4.04	4.04
Wind Speed (1 Hr | 10 m)	kts	0.00	0.00	0.00	0.00	0.00	0.00
Mooring 1 - Vert (N)	Mean	357957.00	325443.00	665301.00	359872.00	328860.00	675002.00
	STD	34752.00	35568.00	46368.00	54225.00	54140.00	86526.00
	Max	447491.00	420407.00	846857.00	518525.00	492560.00	1003828.00
	Min	236988.00	210530.00	531995.00	199577.00	173007.00	443792.00
	Tz	17.38	17.39	17.25	16.75	15.95	16.67
Mooring 2 - Vert (N)	Mean	364835.00	313900.00	649386.00	365475.00	317246.00	658507.00
	STD	29658.00	33167.00	44005.00	47072.00	50297.00	82150.00
	Max	441609.00	402503.00	819945.00	503715.00	469582.00	967841.00
	Min	260402.00	205735.00	521572.00	223099.00	170007.00	435427.00
	Tz	17.64	17.47	17.01	16.83	15.82	16.74
Mooring 3 - Vert (N)	Mean	599884.00	497609.00	522742.00	606136.00	498434.00	523448.00
	STD	29421.00	15120.00	19463.00	54363.00	26022.00	34780.00
	Max	717106.00	547590.00	576400.00	815947.00	587942.00	620082.00
	Min	512179.00	447922.00	469945.00	452621.00	413158.00	431402.00
	Tz	17.57	18.56	19.14	17.05	17.84	19.15
Mooring 4 - Vert (N)	Mean	649168.00	550282.00	527125.00	658136.00	552618.00	527817.00
	STD	35857.00	20023.00	22685.00	66438.00	35593.00	40062.00
	Max	793041.00	623512.00	591048.00	916729.00	684431.00	641682.00
	Min	544130.00	484941.00	463856.00	475876.00	441359.00	415401.00
	Tz	17.32	18.02	18.61	16.82	17.43	18.32
Mooring 5 - Vert (N)	Mean	576764.00	601968.00	384882.00	583912.00	611160.00	388067.00
	STD	28024.00	30806.00	26980.00	54797.00	60014.00	60106.00
	Max	687429.00	721419.00	454020.00	784875.00	829110.00	554995.00
	Min	493258.00	510598.00	295088.00	433963.00	442857.00	208570.00
	Tz	17.64	17.33	17.30	16.74	16.89	16.60
Mooring 6 - Vert (N)	Mean	552490.00	591741.00	376660.00	558013.00	600369.00	380089.00
	STD	23929.00	29389.00	25033.00	46735.00	57173.00	55379.00
	Max	646157.00	704578.00	441159.00	728889.00	806399.00	533209.00
	Min	479708.00	503984.00	293366.00	427350.00	437282.00	213003.00
	Tz	17.65	17.33	17.38	16.82	16.74	16.53
Mooring 7 - Vert (N)	Mean	411867.00	530768.00	498271.00	413482.00	532643.00	499165.00
	STD	30620.00	22773.00	17686.00	49548.00	41208.00	28390.00
	Max	492428.00	593929.00	558195.00	555300.00	646209.00	598500.00
	Min	306676.00	469151.00	439233.00	264181.00	420638.00	406048.00
	Tz	17.72	19.25	18.19	16.82	18.85	17.67
Mooring 8 - Vert (N)	Mean	374830.00	481460.00	506588.00	377405.00	482051.00	507879.00
	STD	33332.00	22972.00	20664.00	52908.00	40868.00	34912.00
	Max	461224.00	546739.00	583829.00	528087.00	597710.00	638479.00
	Min	258727.00	416286.00	439076.00	218207.00	367871.00	400193.00
	Tz	17.30	18.61	18.02	16.75	18.41	17.35

Figure D-13 Vertical Anchor Load Summary – Mooring Intact – 10 Year Swell - Production

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NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-10
Anchoring and Mooring Considerations for an OTEC Plant

OTEC-2010-001

17 September 2010

Prepared for:

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Anchoring and Mooring Considerations for an OTEC Pilot Plant

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Abstract -- Ocean Thermal Energy Conversion (OTEC) plants require placement at locations and water depths that provide the required thermal difference between warm surface waters and cold deep waters for efficient operation. The most favorable locations are frequently near tropical islands or atolls of volcanic origin. These locations generally have steep slopes, irregular bathymetry and uncertain sediment thicknesses. These sites present interesting challenges for anchoring and mooring such plants to meet wind/wave and extreme event criteria. The various bottom conditions at potential anchor locations may require different anchor solutions at each location. This paper describes possible anchor design solutions for an OTEC pilot plant planned for installation off Oahu, Hawaii to illustrate the design alternatives and choices.

INTRODUCTION

The Navy views Ocean Thermal Energy Conversion (OTEC) technology as a potentially viable means to reduce dependence on fossil fuel and associated release of greenhouse gas emissions at Navy bases located in tropical areas, including Naval Support Facility Diego Garcia and facilities in Hawaii and Guam. The Naval Facilities Engineering Command (NAVFAC) OTEC Program is structured to advance commercialization and promote future development of OTEC technology for Navy applications.

While OTEC has a relatively long history of development and demonstration testing, it is only recently that critical technologies have matured to the level needed for commercially viable OTEC facilities. These key technologies include offshore platforms, deep water anchors and moorings, heat exchangers and cold water pipe configurations and fabrication.

The U.S. Navy is conducting feasibility, planning and preliminary design studies for a five to ten megawatt OTEC pilot plant at a notional location on the southwest side of Oahu, Hawaii. Fig. 1 provides a 3D view of an 8 leg

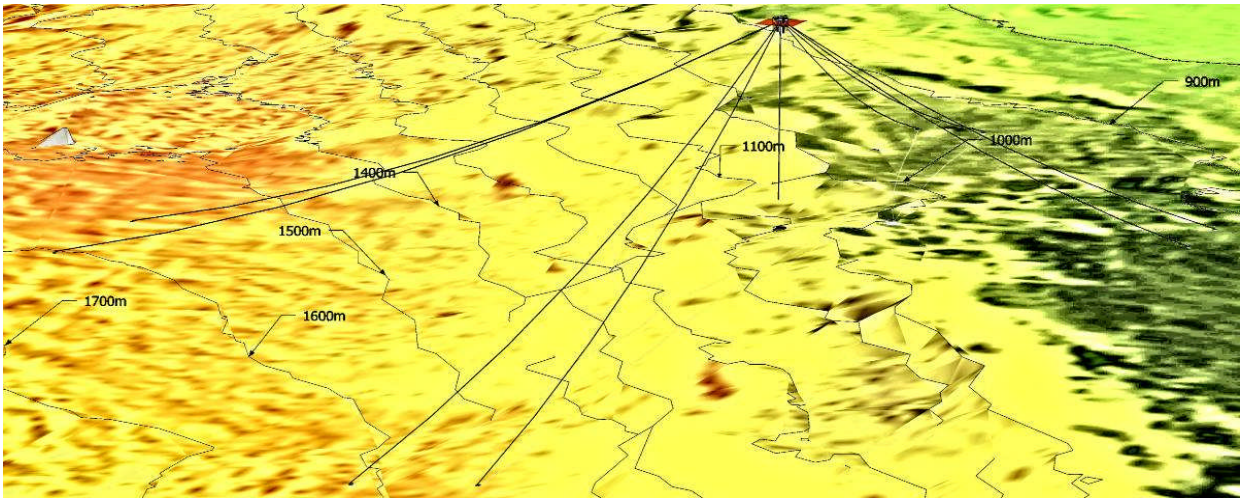


Fig. 1 OTEC Pilot Plant Mooring System

mooring system for an OTEC Pilot Plant located in 1,100 meters of water. This view illustrates the complex seabed condition at the site. Four of the legs are in about 850 meters water depth and four are in waters near 1600 meters deep, resulting in a substantially asymmetrical mooring configuration.

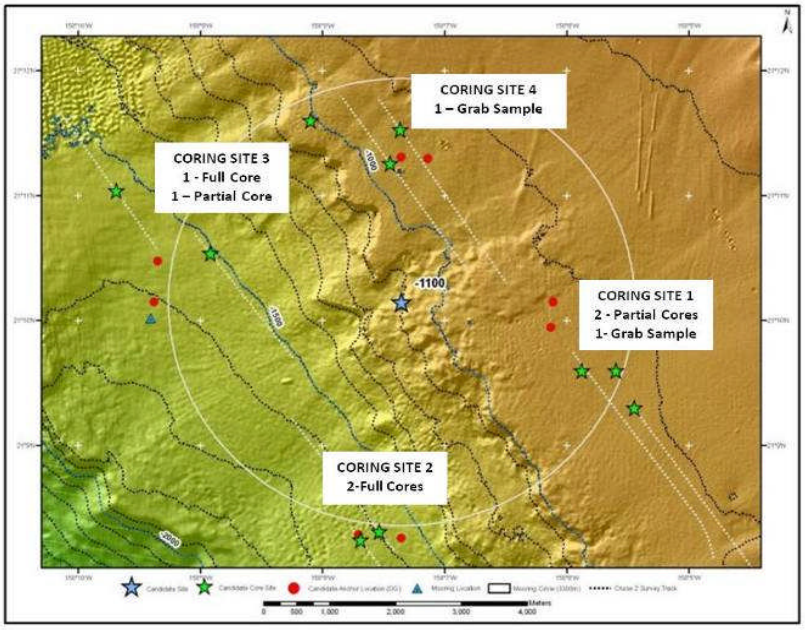


Fig. 2 Core Locations OTEC Hawaii Site

The challenges for the anchor and mooring systems designers concern the different depths at desirable anchor locations, the bottom slopes, the locations of the areas with sediment and the availability of suitable vessels for installation of the anchors and mooring system for potential anchor candidates. These conditions require creative approaches to the design of the anchor and mooring system and can result in a different anchor solution at each anchor location. One size or type of anchor for all anchor locations is not necessarily the best solution.

SEAFLOOR CHARACTERISTICS AND PROPERTIES

During March and May, 2010, the NAVFAC Engineering Service Center contracted for seafloor surveys to be conducted by SST and the University of Hawaii at a candidate OTEC Pilot Plant site off Barbers Point, Hawaii. Details of the site survey are provided in a companion paper [1]. The data collected include high-resolution bathymetry, sidescan imagery, subbottom profiles and sediment cores. Core locations are shown in Fig. 2 relative to the anchor locations selected. The survey showed terraced bathymetry with varying depths of sediment on the terraces and steep, rugged slopes separating the terraces. Geophysical measurements suggest adequate sediment depth at three of the four anchor locations. The OTEC Hawaii Pilot Plant seabed consists of predominantly silt mixed with minor fine sand, and a few thin layers of fine sand. There is very little core data available and what there is extends to about 3m depth at Sites 2 and 3. Standard suites of laboratory tests to determine engineering properties have been performed on the little core material recovered [1]. One 80cm sample recovered at Site 1 shows strength properties consistent with that shown by cores 2B and 3B. The soil strength profiles in Fig. 3 were used for skirted gravity anchor analysis and the assumed soil profiles in Fig. 4 were used for drag anchor analyses. Soil profiles 1 and 2 represent soil strength profiles for typical pelagic sediments at this water depth. These relationships were derived from tests of deep cores during Glomar Explorer surveys during the 1970's and are provided in the Navy Geotechnical Handbook [2]

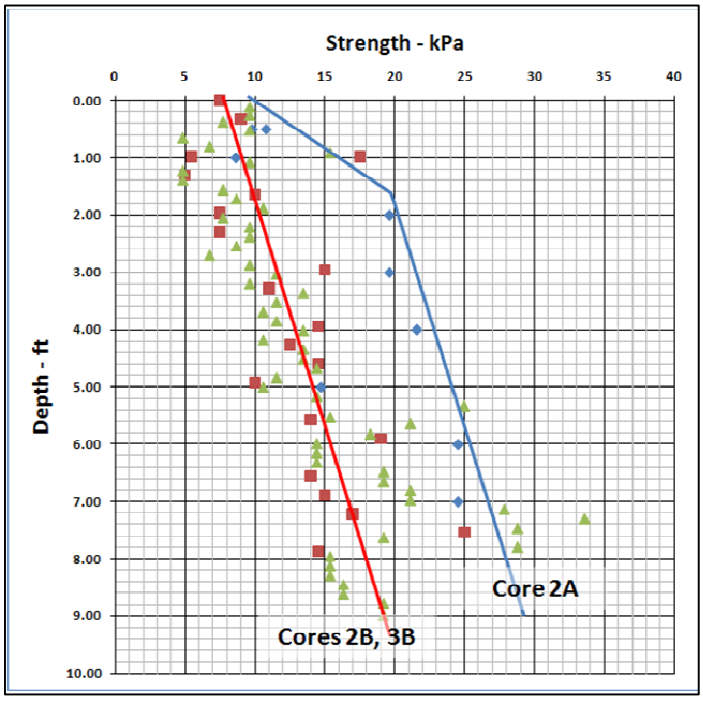


Fig. 2 OTEC Site Core Data

for use when data are unavailable. Drag embedment anchors can penetrate several tens of meters in this material type and unless additional data from cores and CPT are collected in a subsequent survey these strength profiles will be used to size anchors recognizing that conservatism is required. Risk is increased because the actual thickness of sediment overlying rock is uncertain. Thickness could vary from a few meters at Site 4 to more than 25 meters at sites 2 and 3. Geophysical data are being reanalyzed to refine the estimates.

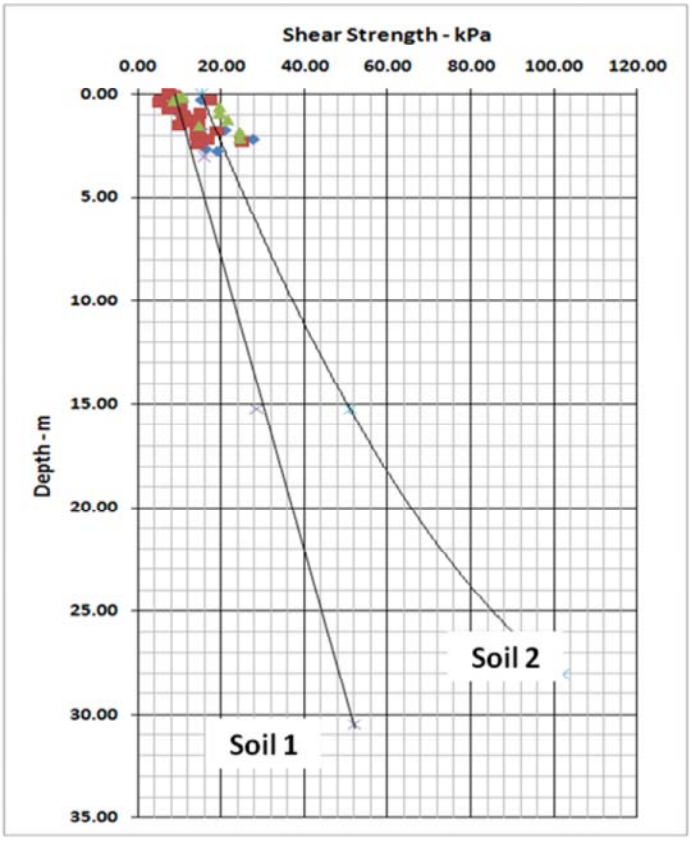
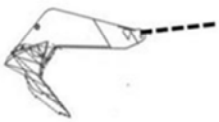
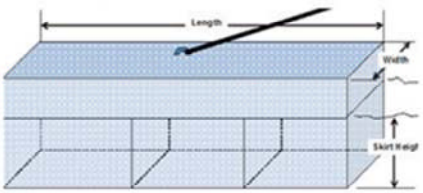


Fig. 3 OTEC Shear Strength Profiles For Drag Anchor Analysis

MOORING AND ANCHORING SYSTEMS

The design of the mooring and anchoring system is an iterative process that is still ongoing for the OTEC Hawaii plant. The difficult site conditions, which are unlike those for most offshore platforms, increase the complexity of the process. Ideally the mooring is configured uniformly to minimize loads and cost and then anchors are sized to satisfy the loads. At a typically heterogeneous OTEC site such as Hawaii, the positions of suitable anchor locations may drive the mooring configuration and leg design. Bathymetric, geophysical and the sparse physical core data were used to identify sites with slopes less than approximately 5 degrees and with sufficient sediment to enable use of conventional anchors. Various taut (polyester) and catenary (wire) mooring leg configurations were evaluated to determine loads and cost for both Pilot (25 year storm) and Production Plant (100 year storm) installations. The eight leg mooring shown in Fig. 1 and 2 is one example of a configuration that attempts to site anchors in suitable conditions that result in loads being manageable from both anchoring and installation perspectives. This configuration was used as the basis for the following anchoring analysis.

Table 1 OTEC Anchor Options

Anchor Option	Features
Drag Embedment Anchor 	- Sizes available to 60 mT - High efficiency in mud ~30 - Deep penetration - Continuous capacity with drag - Proof test required
Tandem Drag Embedment Anchors 	- Capacity of tandem anchors 3X capacity of a single anchor - Requires stable anchors to function properly - More complicated installation
Skirted Gravity Anchor 	- Shallow penetration – less sediment required - Skirts engineered for optimal capacity - Heavy lift capability required - No proof test required; full capacity on placement - Precise placement

There are many types of anchors available, including drag embedment, pile, plate gravity and skirted gravity anchors [3]. In the 800-1600m water depth at the OTEC Hawaii site and with the bottom conditions that could consist of a few to several tens of meters of soft sediment over rock, the only options considered herein are drag embedment and skirted gravity anchors. Simple gravity anchors are very inefficient and can hold anywhere

from 1/2 to 1 times net anchor weight on clay and sand respectively. The addition of skirts to a gravity anchor can increase capacity substantially.

Only two companies manufacture drag embedment anchors with the requisite performance and in sizes necessary for OTEC. They include Bruce Anchor LTD and Vryhof Anchors. Fig. 5 and 6 show the performance of the Bruce MK4 anchor in both soils shown in Fig. 4. These plots were created using procedures developed for the Navy [4,5] and validated against full scale data. The lower end of each curve represents the maximum predicted depth of the anchor fluke tip for an anchor-chain leg.

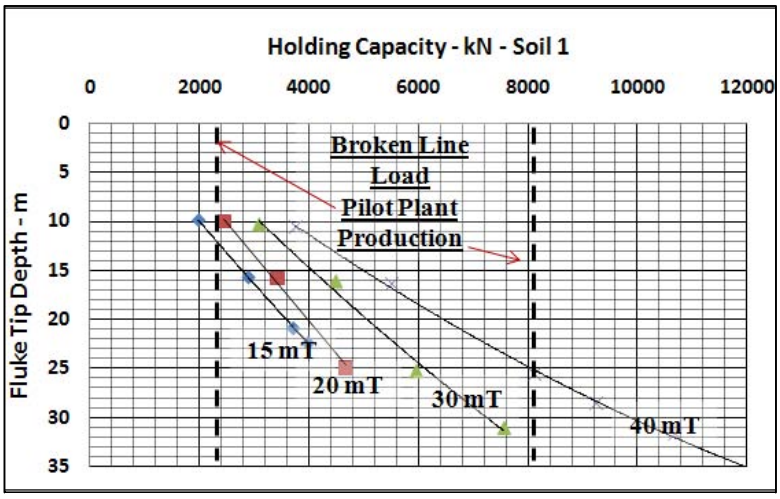


Fig. 5 Bruce FFTS MK4 Holding Capacity – Soil 1

A larger anchor capacity in soft soil can be achieved with a wire instead of a chain segment at the anchor because the anchor-wire system will penetrate about 20% deeper in these sediments; however there is insufficient sediment thickness information to justify use of wire.

The broken line load for both the Pilot and Production Plants represents the maximum line tension at the seafloor for the 8 leg mooring system depicted in Fig. 1.

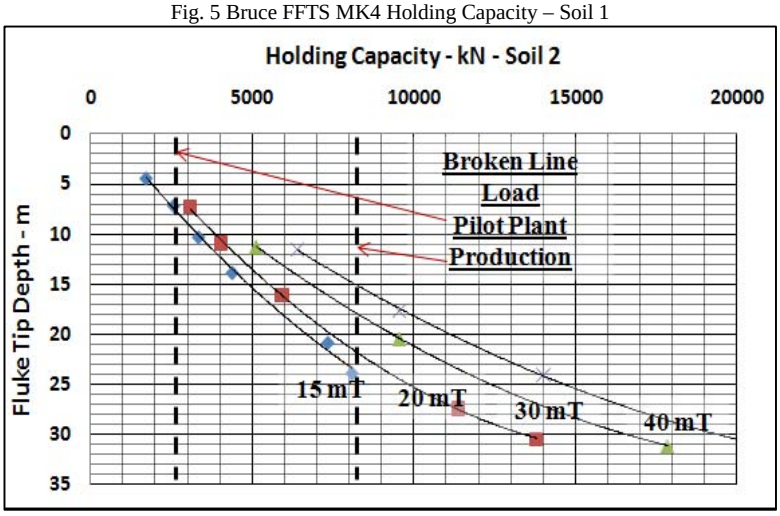


Fig. 6 Bruce FFTS MK4 Holding Capacity – Soil 2

In Soil 1, a 15 metric ton (mT) anchor would suffice for the Pilot Plant and only require 12m of sediment over rock; however, if a single size of anchor is selected that satisfies both Pilot and Production loads then a 40mT size is required, provided that there is sufficient sediment for the anchor to develop the production load. Twenty-six meters of Soil 1- type sediment are probable at two of the anchoring sites but uncertain at the others.

Increasing the number of mooring legs to three per corner should reduce the single-broken-line design load to less than 5000 kN. This greatly reduces the sediment thickness requirement for either soil type analyzed to less than 15 meters. This benefit needs to be traded against the likely increased cost of deck machinery and installation cost.

Though more complicated to install, another means of reducing the sediment requirement is the use of tandem anchors, two on a single leg per corner, as illustrated by Table 1. For example, two 15mT anchors have a greater fluke area than one 40mT anchor and tests [6] of stable drag embedment anchors hooked in tandem show that tandem anchors can hold three times as much as a single anchor, or a 50% increase in system capacity. This is an option for sites with lesser sediment.

A drag anchor performs optimally when the relative line angle at the seabed is zero degrees; however, clump weights or longer mooring lines might be required to create this condition. In both Soils 1 and 2, the effect of elevated seabed line angles on capacity was checked and the effect is modest, with a a reduction in holding capacity of about 2.5% at a 5 degree line angle and 6% at 10 degrees. This equates to about 70-140mT of clump or line weight that can be eliminated from the Production mooring system depending on the whether a 5 or 10 degree line angle is accepted at maximum load.

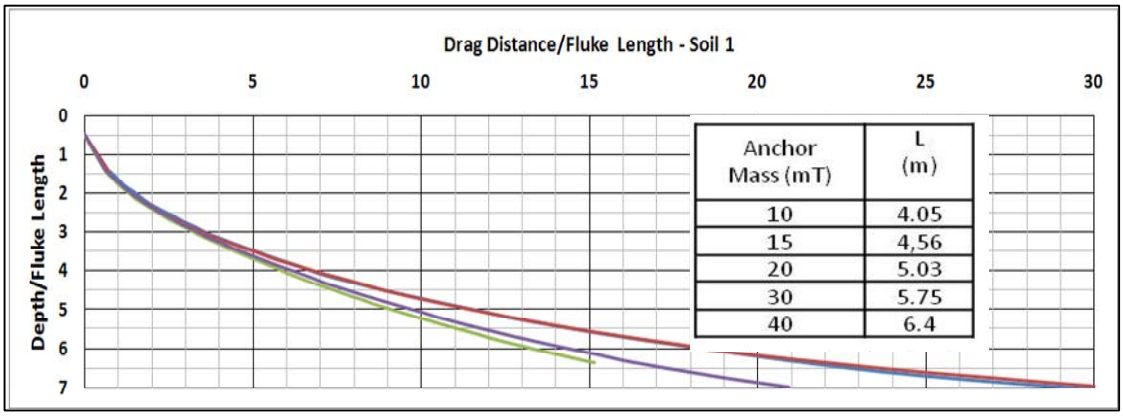


Fig. 4 Non-Dimensional FFTS MK4 Anchor Drag

Another criterion for selecting anchor size is drag distance to achieve target design load. Fig. 7 provides a non-dimensional plot of Bruce FFTS MK4 anchor drag distance versus fluke tip depth for Soil 1. The lower curve is for the largest size but for all practical purposes the curves are similar in this soil and for Soil 2. Although multiple anchor sizes can satisfy a design load requirement, a larger size might be appropriate since it requires less drag distance and less penetration depth to sustain the load.

This exercise in sizing drag embedment anchors for the OTEC Hawaii illustrates that the designer must be prepared to explore different options for selecting and sizing anchors for an OTEC site.

- Drag embedment anchors are possible for this complicated site but the optimal anchoring solution may be different anchor sizes, and perhaps tandem anchors, at some anchor locations.
- The addition of a third leg at each corner for the Production plant mooring will reduce the design load substantially, which reduces the sediment thickness requirement.
- Acceptance of an elevated seabed line angle at the maximum broken line load will reduce the weight of the installed mooring leg without significantly affecting anchor holding capacity.
- If two anchor sizes are capable of satisfying a design load, the larger (more expensive) anchor, requires less drag distance and sediment depth.

Additional geotechnical data and refined analysis of the geophysical data might allow a more accurate design. However, because this site and other potential OTEC sites are typically complicated with variations in sediment type, strength and thickness across the site, the design must be conservative, and the probability of realizing significant economy by highly refining the design is small. In situations like this, risk can be reduced by oversizing the anchors, being prepared to back up the anchors if they fail a proof test or conducting small-scale tests of at least two sizes of the same anchor. Small scale testing at those anchor locations with inadequate sediment data is the best means of quantifying anchor performance.

SKIRTED GRAVITY ANCHORS

A skirted gravity anchor, shown schematically in Table 1, is an option for one or more of the sites where sediment thickness might be insufficient for drag anchors. The addition of skirts to a simple gravity anchor mobilizes shear strength in a cohesive soil and adds the weight of trapped soil to increase sliding resistance in a frictional soil, thus increasing holding capacity considerably. However, the wet weight of the anchor must be large enough to force skirt penetration, and there must be sufficient sediment depth to accommodate the penetration of the skirts.

Skirted gravity anchors weighing (wet) up to 270 mT were analyzed for this OTEC application. The procedures, relationships & failure modes used in this analysis follow Navy Handbook guidance [2]. Parameters were varied while maintaining a factor of safety (generally a ratio of capacity to load) of at least 1.0 for each failure mode, and equal to 1.0 for whatever mode becomes the defining critical failure mode for the particular configuration. The modes considered were: short-term & long-term sliding, overturning, bearing failure (with & without application of the line load) and incomplete penetration of the skirt & shear keys.

Parameters varied in this analysis were:

- Rectangular block height (point of application of line load, constant H = 0.9m)
- Depth of block base (constant $D_b = 0$)
- Anchor total wet weight (135mT < W_{bf} < 270mT)
- Skirt/key height (penetration depth, z_s = 2m, 3m, 4.3m)
- Rectangular block length-to-width ratio (R_{LW} = 1, 1.5, 2, 3)
- Line load vertical component-to-horizontal component ratio (R_v = 0, 0.5)
- Rectangular block base area (A minimized while all FS > 1)
- Lateral capacity (F_h maximized while all FS > 1)
- Seafloor slope: (6 degrees, 0, –6 degrees, positive downward toward pull)
- Cohesive soil strength (linearized approximations of data from Cores 2A, 2B and 3B, as given in Fig. 3.

Results showed that the holding capacity of skirted gravity anchors varies from less than their weight to over double their weight, with dependencies:

- Increasing line angle (R_v) decreases capacity
- Increasing slope (downward toward the pull) decreases capacity
- Increasing soil strength decreases capacity, because the penetration capability of the anchor skirts is reduced, thereby also reducing the amount of increase in capacity that comes from the entrapped soil.

The tools used in this analysis can provide optimum anchor parameters and performance estimates for specified site and loading conditions. For example, the following parameters and estimates were obtained within the overall constraints of a flat seafloor and an anchor wet weight of 250mT with the line attached 0.9 m above grade. For the weaker strength profile (Cores 2B & 3B), a near-optimum configuration consisting of 3 meter-deep skirts and keys and a square shape 20m on a side (Fig. 8) is estimated to hold about 630mT horizontally; the same configuration at a line angle above horizontal of about 26.6 degrees (R_v = 0.5) is estimated to hold about 450mT. For the stronger strength profile (Core 2A), a configuration consisting of 2-m-deep skirts and keys (Fig. 9) and a square shape 21m on a side is estimated to hold only about 450mT horizontally, whereas a rectangular shape 36m by 18m (long dimension aligned with line pull, making it more resistant to overturning) is more nearly optimum and estimated to hold about 630mT horizontally.

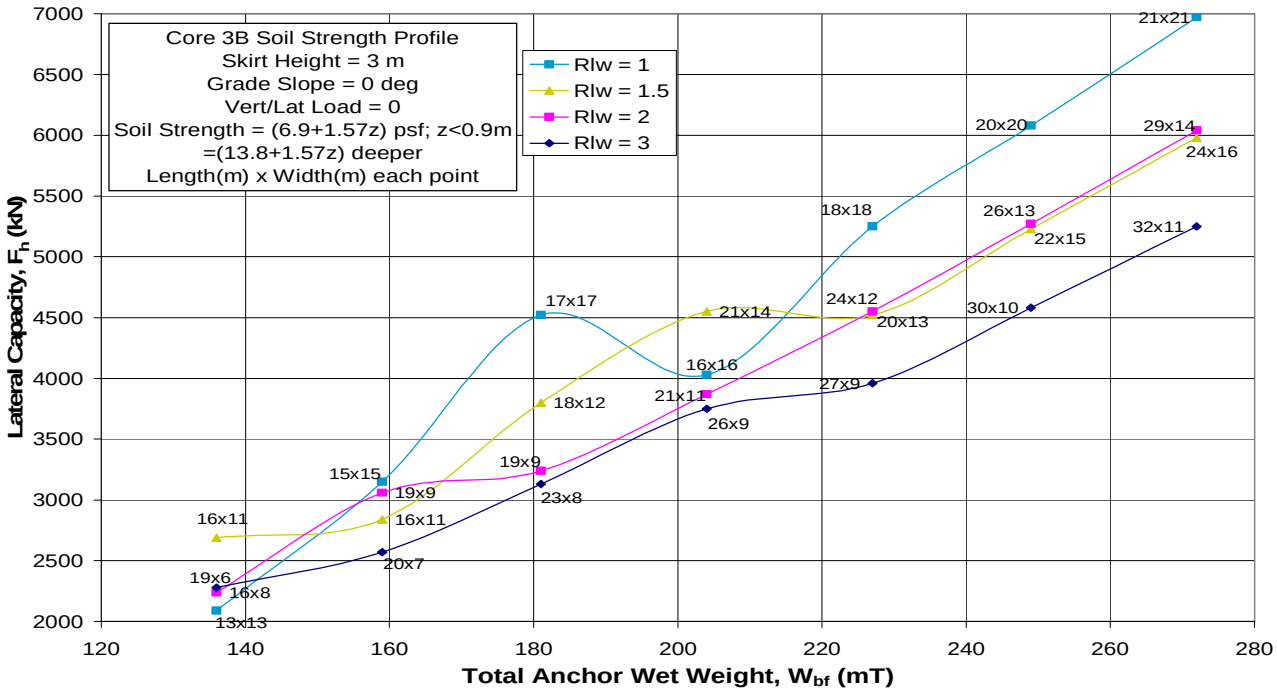


Fig. 5 Skirted Gravity Anchor Performance: Core 2B & 3B Soil.

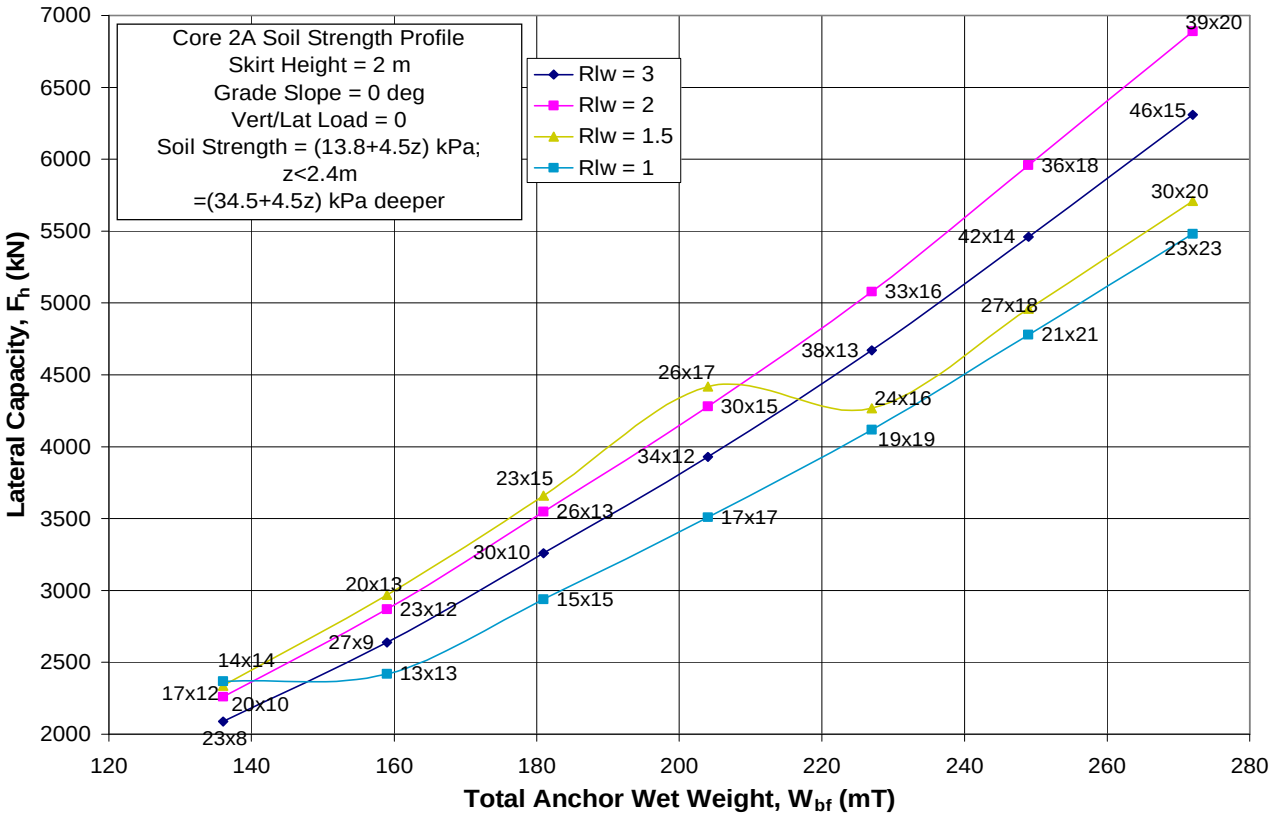


Fig. 6 Skirted Gravity Anchor Performance: Core 2A Soil

CONCLUSIONS

Clearly there are a multitude of possibilities that remain to be explored to finalize the selection and sizing of drag anchors, but the analysis provided herein shows that there are possible solutions using single or tandem drag embedment anchors and skirted gravity anchors that satisfy the design conditions.

The complex and varied seabed condition at the OTEC Hawaii site should not be considered atypical, the requirement for a large quantities of water at substantially different temperatures often leads to sites with strong currents, rough topography, and varied bottom materials and thicknesses of soil over rock. At such a site, suitable anchor locations may drive the mooring configuration and leg design. Furthermore, an optimal anchoring system can entail different types and/or sizes of anchors at each anchor location to accommodate the soil layer thicknesses and properties.

ACKNOWLEDGEMENTS

The Naval Facilities Engineering Command (NAVFAC) Engineering Service Center, Port Hueneme CA supported the Hawaii site survey and the anchoring analysis for the OTEC Hawaii Pilot Plant. The Navy has supported comprehensive anchor technology developments, analysis, testing and documentation over the last several decades that were fundamental to the OTEC Pilot Plant analysis. The Oregon Wave Energy Trust supported an exhaustive recent survey of up-to-date developments in anchoring and mooring technologies. The results of all of these efforts served as the basis for selecting and analyzing the most attractive choices for the OTEC Hawaii Pilot Plant site.

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NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-11
Remora Requirement Revision April 2010
OTEC-2010-001

17 September 2010

Prepared for:

Naval Facilities Engineering Command
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NavFac OTEC Remora Requirements

Document Identifier: OTEC04052010-RemoraReqt-PG

Requirements

1. A Remora is a modular spar-like structure housing seawater pumps, ducts and intake screen, and ammonia heat exchangers, pumps and pressure vessels that produce ammonia process vapor suitable to generate 5 MW net electrical power. It can be removed from the central otec platform, without disturbing the cold water intake pipe, to be overhauled in a shipyard.
2. OTEC platform shall be able to operate with 1 or 2 remoras attached.
3. Overall OTEC plant shall be designed IAW ABS class rules for Floating Production Installation.
4. General arrangement should reduce the risk for construction and operation of anticipated commercial-scale remora.
5. Warm seawater intake (WSW) screen velocity < 0.15m/sec, mainly (+/- TBD degrees) horizontal flow.
6. Discharge depth for Warm Seawater (WSW): > 30m below the WSW intake
7. Discharge depth for Deep Seawater (DSW): >60m deep, adjustable to 90m deep due to environmental impact unknowns.
8. Design life = 20 years for hull, shorter for HX
9. Able to change seawater pumps and ammonia pumps while connected to center platform
10. Meet the following criteria during docking / undocking / transport:
    - Size and drafts when floating horizontal suitable to be drydocked or maintained in Hawaii shipyards.
    - Able to perform > one dozen docking/undocking evolutions during design life. This affects towing speed, global bending stress, sea state when floating horizontally, etc.
11. Contain all ammonia process equipment, except turbine generators or shared components such as purification equipment or storage volume.

12. Ammonia system to meet ANSI B31.3, ANSI B31.5, and ANSI K61.1 standards, or justify why standard is not met.

13. Constructable in U.S. or foreign yards.

14. When attached to center platform, survive Barbers Point Oahu 25-year design metocean conditions: 4.3m significant wave with peak period 10.6 seconds. Maximum current = 0.72 m/sec for upper 100m. These values are from Design Basis Design Rev 4 dat4ed 10 Mar 2010. Swell = 4 m at 20 sec.

15. Design Seawater temperatures: WSW = 25.7˚C (depends on WW intake depth), DSW = 4.1˚C (HI average annual)

16. Flow per remora: Not to exceed 23 m^3/sec of WSW and 18.5 m^3/sec of DSW.

17. Water passages and heat exchanger watersides shall be inspectable without detaching from center platform.

18. Provide 2 m2 flow area for ammonia downcomers to condensers, and 2 m2 flow area for ammonia vapor risers from evaporators. Provide 25% of this area for ammonia liquid piping.

19. Attachment brackets to platform: Lowest point is 23m below MSL, highest point is 20m above MSL.

20. Use the more conservative assumptions for pump and turbine efficiencies and HX fouling factor as documented within the Remora 2.0 system model.

21. Use a single stage ammonia Rankine power cycle as decided at the 15 Mar 2010 Engineering review Board.

Goals

1. For the commercial plant, the goal is to achieve lowest cost for overall OTEC system. This particularly affects duct size and diffuser geometry. Design choices for the pilot remora should help achieve that goal.

Notes

A. Deep Seawater (DSW) is supplied to the remora from the center platform.

B. Turbine generator equipment will be on the center platform. Electrical equipment may or may not be located on the remora.

C. Payload: Maximum of 240 m^3 of condenser core and 190 m^3 of evaporator core per remora. 4m to 8m tall heat exchangers

D. For concept development, assume heat exchangers have a specific gravity of 1.3, when filled with water and ammonia vapor, and SG = 0.9 for empty HX in air. For shell & tube HX, assume max HX diameter is 4.6m.

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B. Top Level Requirements –Robert Varley

C. Seawater Temperature Data for NavFac OTEC, Steven Rizea, Makai Ocean Engineering, 3 Dec 2009.

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-12
Plume Modeling Report
OTEC-2010-001

17 September 2010

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Makai CEROS OTEC Plume model: 10 MW Pilot Plant Simulations

Greg Rocheleau, Patrick Grandelli Makai Ocean Engineering, Inc. Sep. 9, 2010

This report summarizes modeling of the 10MW mixed discharge OTEC plant operating at the Barber's Point site, using realistic oceanographic conditions provided by the Hawaii Regional Ocean Model.

Background

During 2009-2010, Makai developed an OTEC plume model for waters off West Oahu using the Environmental Fluid Dynamics Code, EFDC, with funding from the Center of Excellence in Research for Ocean Sciences (CEROS/DARPA). EFDC is a 3D hydrodynamic model, chosen for this application because of its fully developed and validated embedded jet-plume model (Choi and Lee, 2007), the freely available source code, and availability of developer John Hamrick. Makai has made significant modifications to EFDC in order to nest the grid within the Hawaii Regional Ocean Model (HIROM) operated by Brian Powell at the University of Hawaii. The HIROM work is funded by a NOAA-led consortium as part of the Integrated Ocean Observing System (OOS) program. HIROM is a time-domain data assimilative "nowcast" model that includes ocean circulation and mixing due to wind, waves, and barotropic and baroclinic (internal) tides. "Data-assimilative" means that the model receives periodic real-time data from installed oceanographic sensors that forces the model to remain accurate at those measured points, preventing the overall calculation from drifting into long-term error. It is the best dynamic model for Hawaii waters presently available. The boundaries of the OTEC plume EFDC computational domain are forced by the conditions calculated by HIROM. Compared to plume models run during during the 1970's and 1980's, these 2010 results are the most representative dynamic otec plume modeling ever performed.

EFDC and HIROM

The Environmental Fluid Dynamics Code was developed by John Hamrick, and is currently maintained by Tetra Tech, Inc. EFDC is a finite-difference, shallow water equation model similar in framework to primitive equation models, such as the Princeton Ocean Model (Hamrick, *personal communication,* 2009), which have been used extensively to model realistic ocean currents in Hawaiian waters (Carter et. al 2009; Holloway and Merrifield 1999; Johnston and Merrifield 2003; Cummins and Oey 1997; Merrifield et. al. 2001; Niwa and Hibiya 2001; Merrifield and Holloway 2002; Johnston et. al. 2003). EFDC solves the three-dimensional, vertically hydrostatic, free surface, turbulent averaged equations of motion. The "turbulent averaged equation" means that mixing due to sub-grid scale turbulence and density induced instabilities (i.e. non-hydrostatic effects) is parameterized as a diffusion term using a set of dynamically coupled equations, known as a turbulence closure model, or in the case of EFDC, the Mellor-Yamada 2.5 turbulence closure scheme.

Figure 1 shows a general schematic of the model developed under the CEROS funded plume study, located near Kahe Point, Oahu. The Makai OTEC plume model (EFDC) has a 200m horizontal resolution. It receives boundary conditions from the HIROM model, which supplies horizontal currents, temperature, salinity, and surface elevation. A simple represention of the OTEC plume is shown as blue,

but the actual velocity and mixing is computed with the embedded Langrangian jet-plume model shown in the right hand side of the figure. As the jet leaves the near-field Lagrangian model, it is calculated by the EFDC grid, which in turn is driven by the surrounding HIROM grid. HIROM is a regional ocean model, which includes barotropic and baroclinic tides (internal waves), as well as data assimilation from surface altimetry satellites, nearshore current meters (ADCPs), and UH gliders. It is state-of the-art and provides the most accurate and advanced oceanographic modeling that is available today. For the NAVFAC simulations the EFDC grid has been moved for the location south of Barbers Point, Oahu near 21.175N and 158.125W as shown in Figure 2.

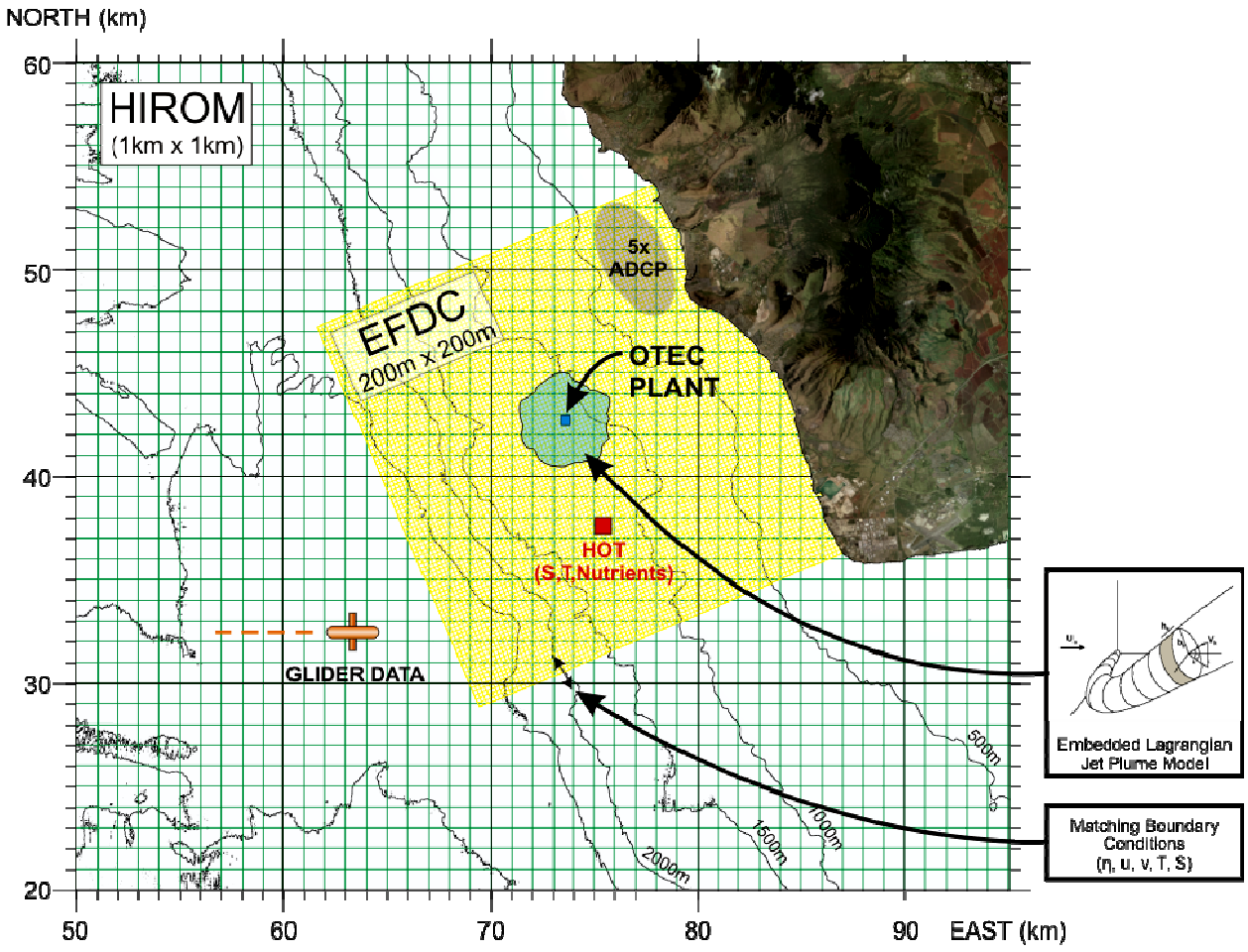


Figure 1 Schematic map of Makai's CEROS Otec Plume study showing the EFDC plume domain offshore Kahe Point, Oahu, within the larger HIROM domain.

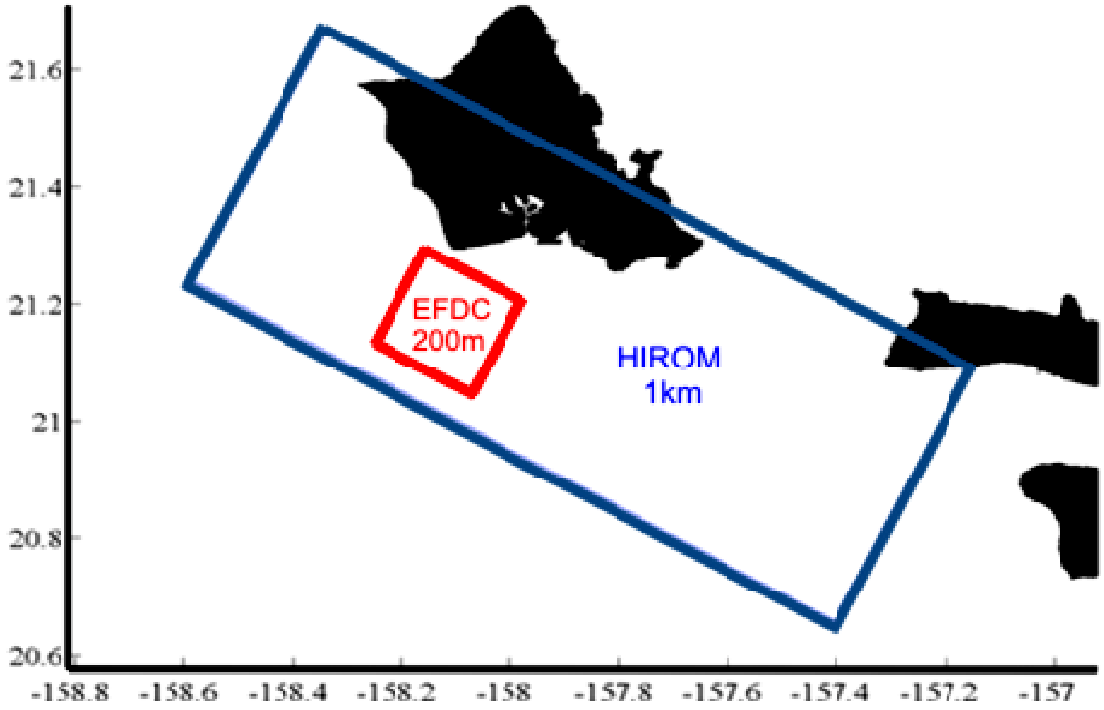


Figure 2 Grid location and resolution used for the 10MW NAVFAC pilot plant modeling.

Open Boundary Conditions and Relaxation Region

HIROM is integrated into the CEROS Plume Model at the open boundaries, where currents, temperature, salinity, and surface elevation are prescribed. Setting the boundaries exactly to HIROM conditions is not practical due to the complexity of the bathymetry, variation in grid resolutions, and subtle differences in numerical schemes between the two models. Doing so over-specifies the EFDC solution (leaving too few degrees of freedom) and results in unstable and unphysical flows. Makai worked with John Hamrick (TetraTech, author of EFDC) to modify the EFDC source code for this nesting application and produce a good agreement between EFDC and HIROM simulations.

Radiation boundary conditions are commonly used in oceanographic boundaries (Carter and Merrifield, 2007), and we utilize them here to force the surface elevation and depth averaged flows in the model (i.e. barotropic mode). Unfortunately, when used alone, this boundary condition (in conjunction with the temperature and salinity boundaries) leaves too many degrees of freedom and is unable to resolve the internal depth varying flows. A data assimilative routine, commonly known as “relaxation”, was implemented at the open boundaries of the grid in order to nudge the CEROS Plume Model towards the known HIROM conditions. This technique, discussed in detail by Carter and Merrifield (2007), Jensen (1998), and Lavelle (2008), replaces any computed variable with the sum of an external value and a fraction of the computed value:

$$\phi = \alpha\phi^{ext} + (1-\alpha)\phi^{*}$$

where α is the assimilative factor (user defined) and $\varphi$is the variable being assimilated.

We provide a comparison of our results in Figure 3, which shows the time series from the center of the EFDC domain and the corresponding ROMs solution south of Barbers Point, Oahu, Hawaii. The time series show good agreement between density and currents. University of Hawaii Professors Mark Merrifield and Brian Powell, experts in Hawaiian internal tides, mixing processes, and ROMs simulations, also concluded that our model shows good enough agreement to the HIROMs model to meet the goal of the CEROS OTEC plume study, which was to simulate the fate of OTEC discharges under varying oceanographic conditions.

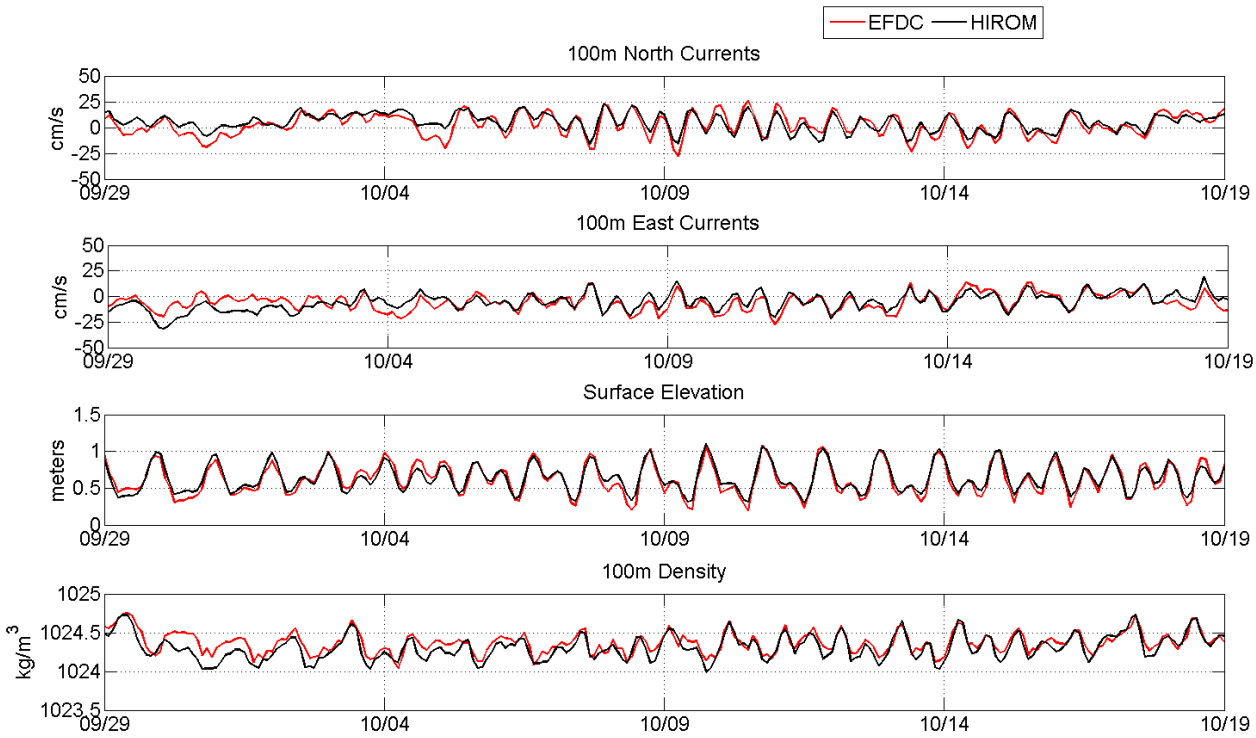


Figure 3 Time series comparison of temperature and currents from ROMS and EFDC taken at the center of the grid used in Makai's CEROS OTEC plume model (~15km south of Barbers Point, Oahu, Hawaii). Simulation was of September and October 2009.

Plume Physics and EFDC Plume Modeling

Thermal discharge plumes are typically divided into three regimes: The near-field, intermediate-field, and the far-field. Near field refers to the region immediately after discharge, when the momentum of the jet-plume is significant and mixing is dominated by shear and vortex entrainment of the surrounding water. As the cold plumes sink (typical discharge temperature is 15 ^{o}C), they become entrained with the surrounding water (which is relatively warm) and lose their downward momentum. This intermediate-field plume is dominated by buoyant forces, and will sink or rise to a level of "neutral" buoyancy. At this

point, the plume's density matches the surrounding water and since the upper water column is highly stratified, the plumes will remain within a constant "neutral" density layer, referred to as their equilibrium depth, as they are transported into the far-field domain. The long range transport and mixing of the plume will become dominated by the diffusion and advection typically found in the ocean.

Embedded within EFDC's hydrodynamic model is a fully developed and validated jet-plume model (Choi and Lee, 2007) capable of computing the near-field and intermediate-field trajectory and average plume properties. Figure 4 shows schematics of the jet-plume model, which uses a finite element method and semi-empirical relations to compute the entrainment as a function of plume radius, plume velocity, plume buoyancy, and the background hydrodynamic conditions such as temperature, salinity, and current. The plume model is coupled to the hydrodynamics through a series or distribution of sources and sinks in the hydrodynamic domain, whose volume and constituent loads are based on the predicted plume entrainment and trajectory. The result is a true "two-way" coupling that allows for accurate computation of the near-field and intermediate-field plume in an otherwise hydrostatic circulation model.

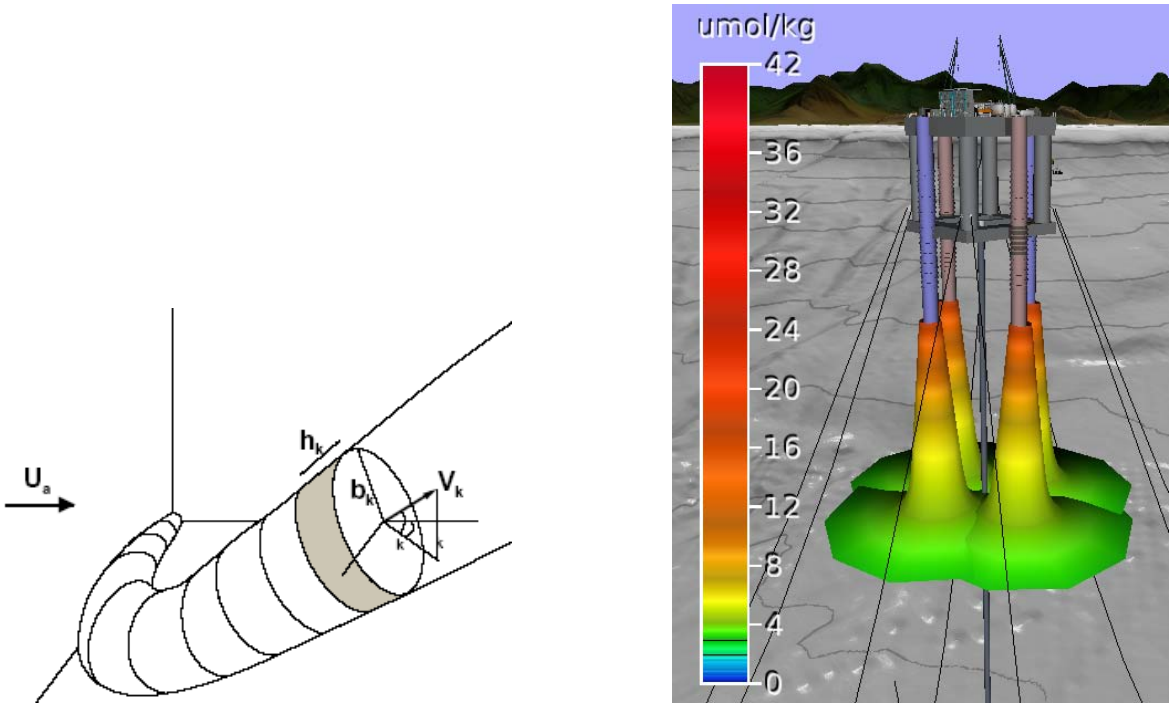


Figure 4 Schematic of the jet-plume model, showing the finite element representation of the plume (left), and the OTEC Jet Plume model (right).

Nitrate Distribution

The supply of nutrients to the photic zone, which could potentially cause harmful algal blooms, has been a major concern when discussing the fate and impact of OTEC discharges. A key question when designing and assessing OTEC facilities is how deep and at what velocity must we discharge the OTEC waters to mitigate this impact. Figure 5 shows the nitrate profile from the Hawaii Ocean Time-Series, which takes monthly casts at Station ALOHA as well as a Kahe Point calibration site (which is very near the proposed OTEC site off Southwest Oahu). The nitrates on the surface are very low, at levels well below 1 umol/kg. Levels at the cold water intake depth (1000-1100m) are at 42 umol/kg. Meanwhile, nitrate levels at the proposed discharge depths (100-200m) are ~3 umol/kg. To reach the ambient nitrate levels at the discharge depths would require an ~15:1 dilution of the deep intake waters. We have incorporated nitrate transport into the hydrodynamic model in order to assess these impacts (we include the physical transport of nitrate, but no biological or chemical processes at this time).

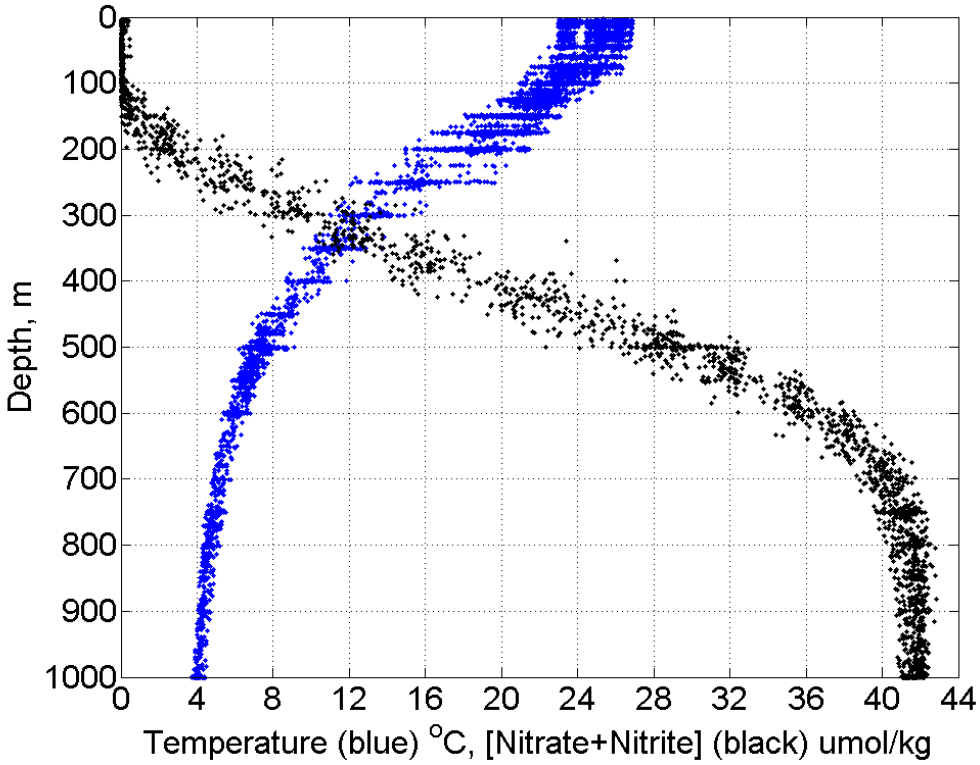


Figure 5 Temperature and Nitrate/Nitrite from HOT Station ALOHA.

Results

Simulation Configuration

Makai has simulated the operation of a 10MW OTEC facility south of Barbers Point Oahu, using the model described above. Conditions for the run were obtained from a HIROM hindcast of September and October of 2009. Discharges were simulated as two mixed (combined cold water and warm water) discharges at 70m depth each with a total flow rate of 44m^3/s (1.3:1 ratio of WW:CW) and a discharge

velocity of 1m/s. The EFDC domain inside the HIROM model had dimensions of 17.5 km x 17.5 km through the entire water column.

Average Properties

The resulting equilibrium depth of the plumes is on average 127m with nitrate concentrations of 2.9 umol/kg, while the ambient nitrate concentrations at this depth are 0.25-1.5 umol/kg. Figure 6 and Figure 7 show a one day average of the nitrate plume at 110m and 130m depth. The plume is evident in the immediate area of the plant, but shows a negligible nitrate signal in the far-field. There is also an increased nitrate level in the grid (light blue-green), due to the background circulation and vertical mixing associated with internal tides, which is similar in concentration to the OTEC plume. This is an important result, showing that the plume nitrate concentrations on the far-field scale are the same as ambient conditions.

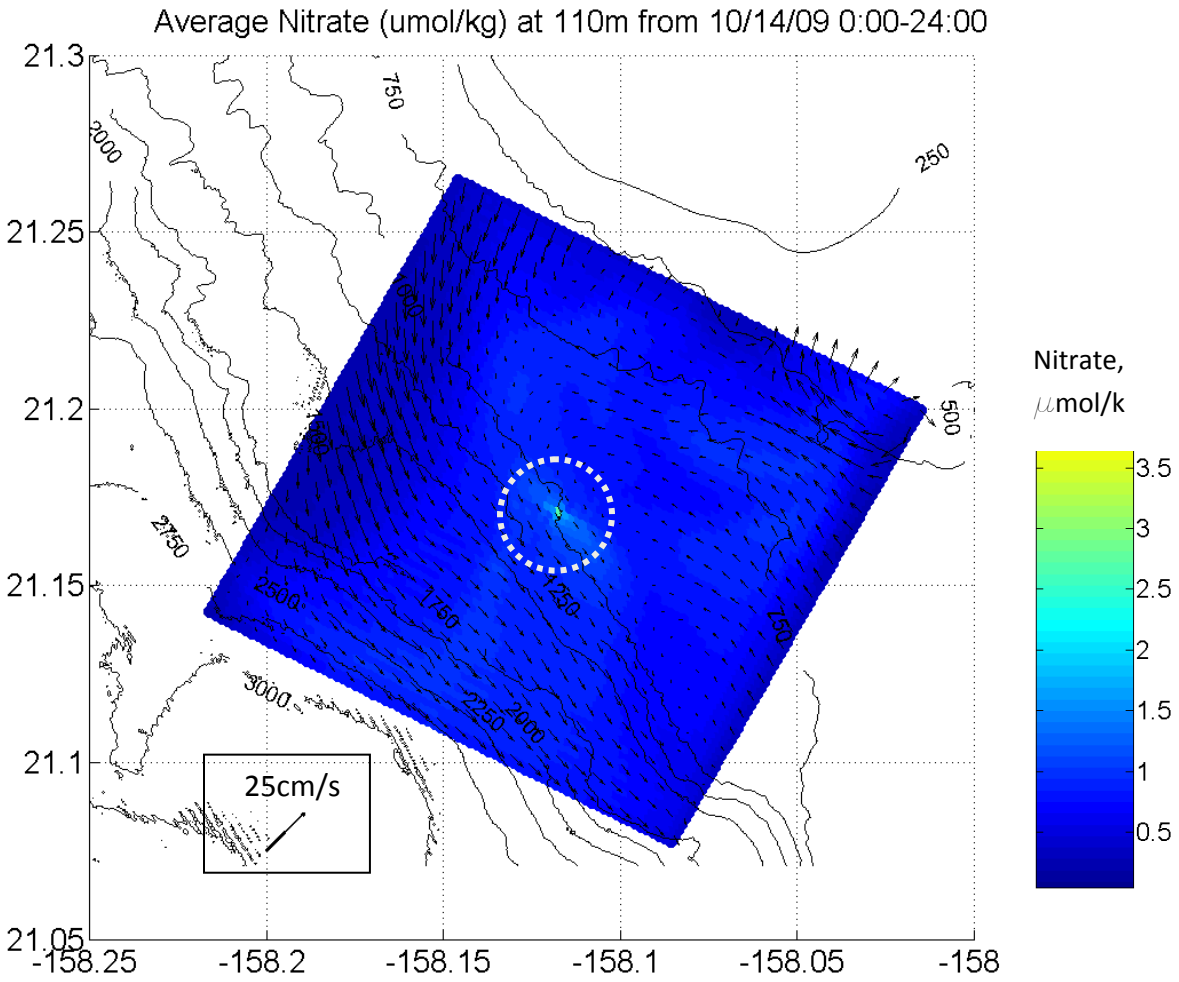


Figure 6 Horizontal plan view of a typical daily average of the nitrate concentration at 110m depth around a 10MW OTEC plant. The location of the OTEC plume is outlined with the white dashed circle.

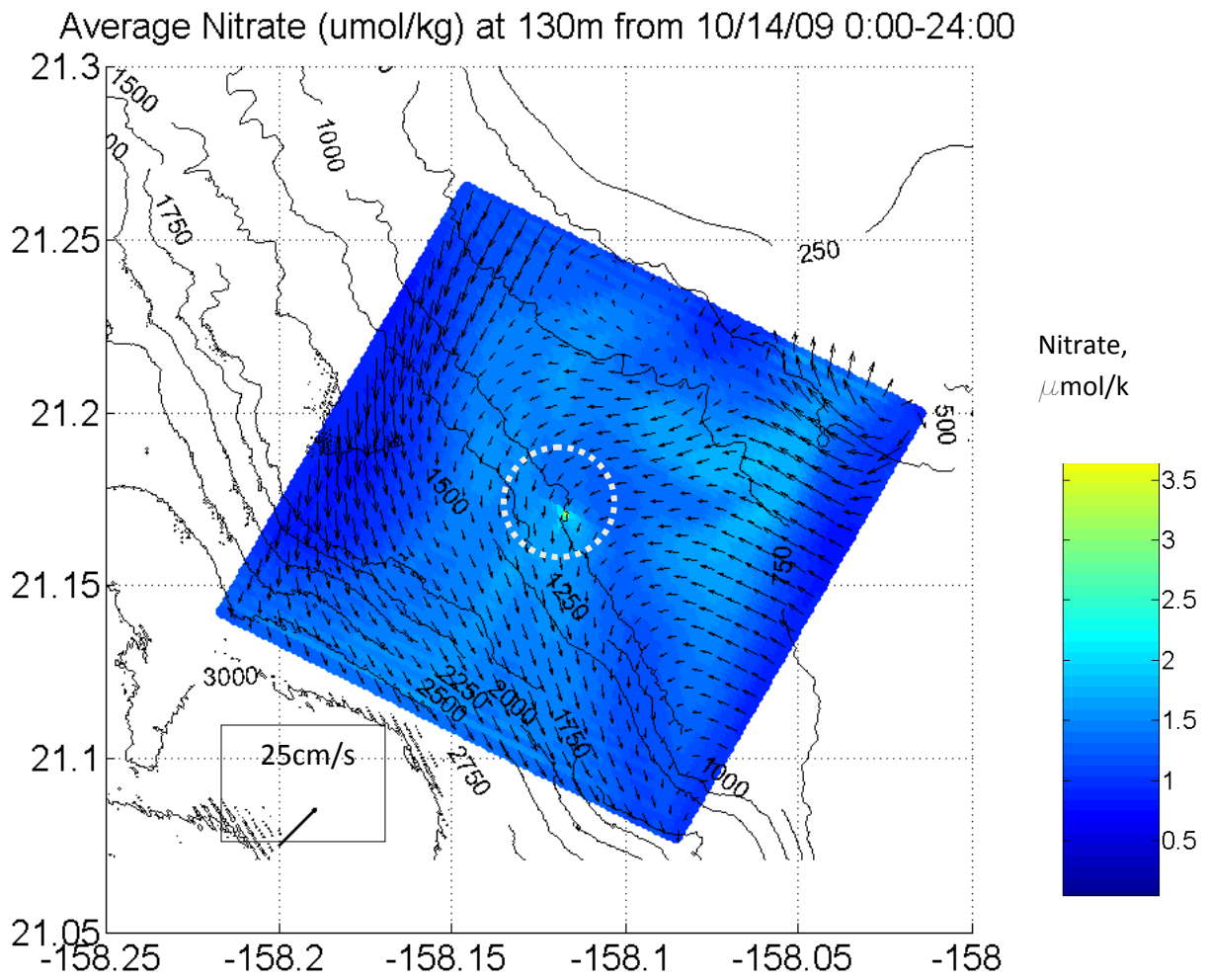


Figure 7 Horizontal plan view of a typical daily average of the nitrate concentration at 130m depth around a 10MW OTEC plant. The location of the OTEC plume is outlined with the white dashed circle.

Figure 8 shows the vertical profile of the average nitrate concentration directly below the OTEC discharge and at a horizontal distance of 440m away from the OTEC plant. There is a slight increase in the nitrate concentration at a depth of 90-150m directly under the OTEC plant. However, the nitrate levels quickly reach the ambient levels as you get farther from the plant, with only a slight perturbation seen in the profile of locations 440m away. Also important to notice, the average nitrate levels are well within the naturally occurring variability measured at HOT (Hawaii Ocean Time-Series) station 1 Kahe Point, and there is almost no discernible modification to the far-field temperature. Only a slight homogenization of the temperature can be found directly below the OTEC plant and at the depth of the plume's neutral density layer (127m).

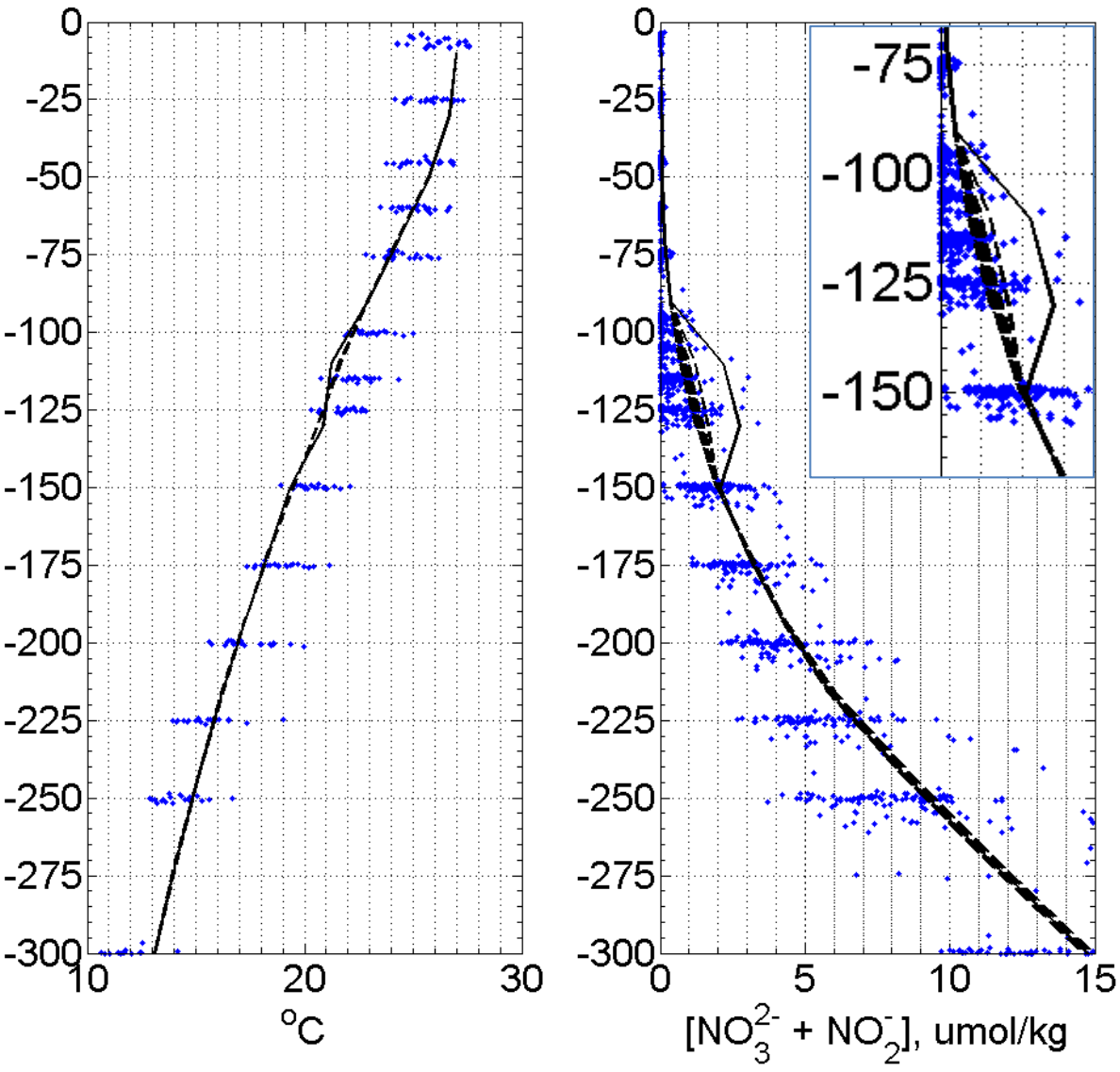


Figure 8 Vertical profile of average temperature (left) and nitrate concentration (right, with inset) directly below the OTEC plant (solid black line), and at radial distances of 440m (dashed black line). Historical observations from HOT station 1 at Kahe Point are shown as blue dots.

Dynamic Properties

The depth and horizontal extent of the plume is significantly modified by the magnitude of the background currents. Stronger currents cause greater entrainment and dilution of the jet-plume as it sinks, which results in shallower but significantly more dilute plumes. Figure 9 shows a close up of an OTEC plant during weak and strong flows (images taken from CEROS OTEC plume study of a 100MW plant), displaying the near-field plume trajectory and concentration and a vertical slice of far-field nitrate. The top image is a snapshot during weak (<10 cm/s) currents and the bottom image is a

snapshot during strong (>50 cm/s) currents. Strong currents force an increased level of turbulent mixing and entrainment (of warm nutrient depleted surface waters), causing the jet-plumes to become diluted soon after being discharged. The increased dilution with warm surface water causes the plumes to find equilibrium at shallower depths, but with significantly reduced nitrate levels compared to the periods with weak currents.

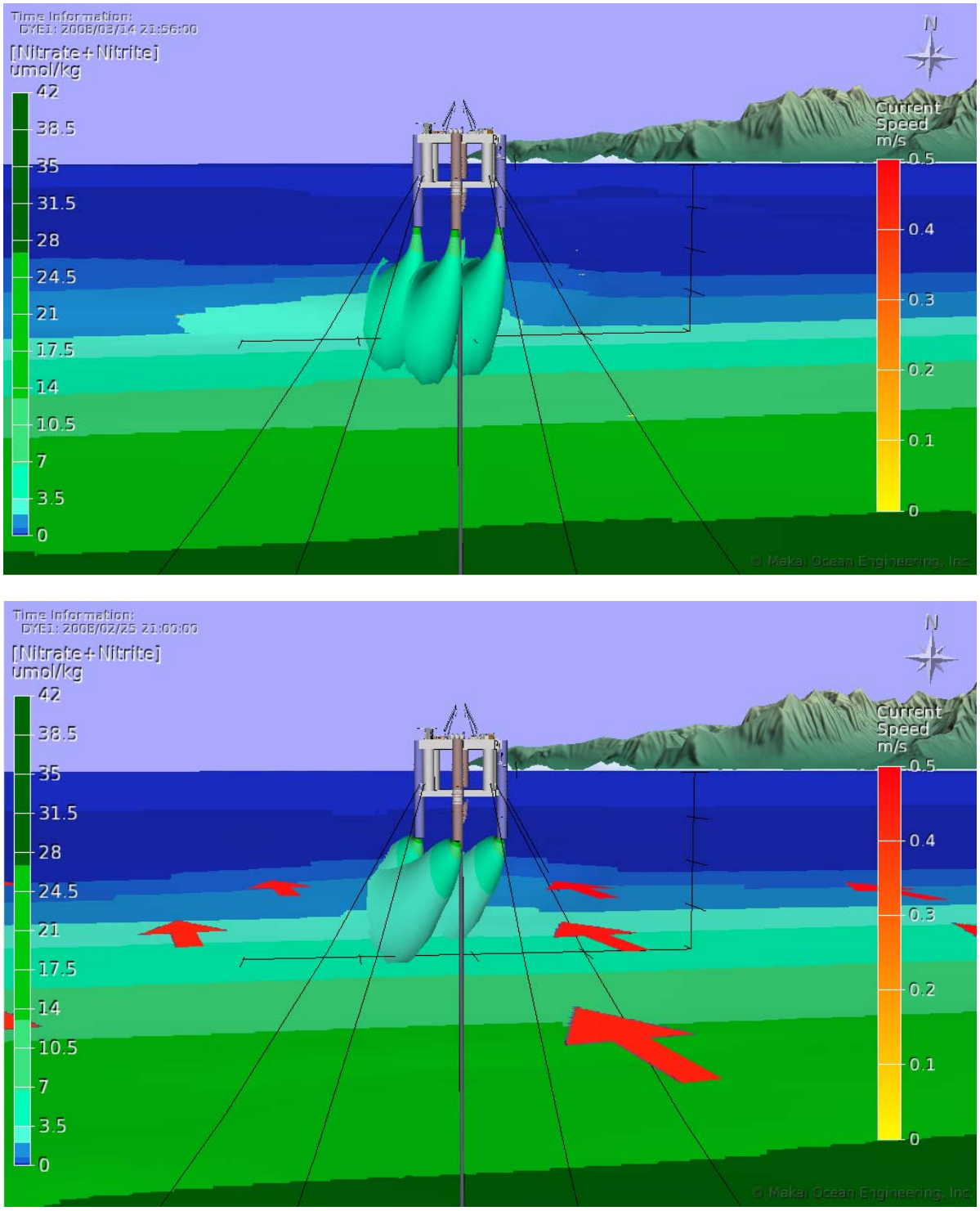


Figure 9 Plume trajectories and nitrate concentrations of a 100 MW otec during <10 cm/s currents (top) and >50 cm/s currents (bottom). The plumes in the faster currents achieve significantly greater dilution which results in a shallower equilibrium depth. These results are from the CEROS OTEC plume study of a 100MW OTEC plant with 70m mixed discharge, 14.57m discharge diameter with outlet velocity = 1 m/s. Warm water flow = 420 m^3/s and cold water flow = 320 m^3/s.

The correlation between the current field and equilibrium depth of the near-field plume for the 10MW pilot plant is shown in Figure 10. The scatter plot shows background current magnitudes, resulting terminal depths, and nitrate concentrations of the near-field plumes taken from the 30 day 10MW pilot plant simulation (each point in the figure represents a 20 min interval, which coincides with the times the jet plume model is updated). When the currents are strong the plume is rapidly diluted with the surrounding (less dense) water, causing them to equilibrate at shallower depth. For example, currents of 30 cm/s produce plumes with a terminal depth of 110m and nitrate concentration of 1.0-2.5 umol/kg. Currents of 0-10 cm/s produce plumes with a terminal depth of 130m and nitrate concentration of 2.5-3.5 umol/kg. In any case, the nitrate values of the plume reaches a level within the naturally occurring variability at a short distance from the "terminal" location of the jet-plume, or within about 200m of the OTEC plant at the equilibrium depth. (please refer to figures 4 and 6 for measured nitrate profiles from the Hawaii Ocean Time-Series).

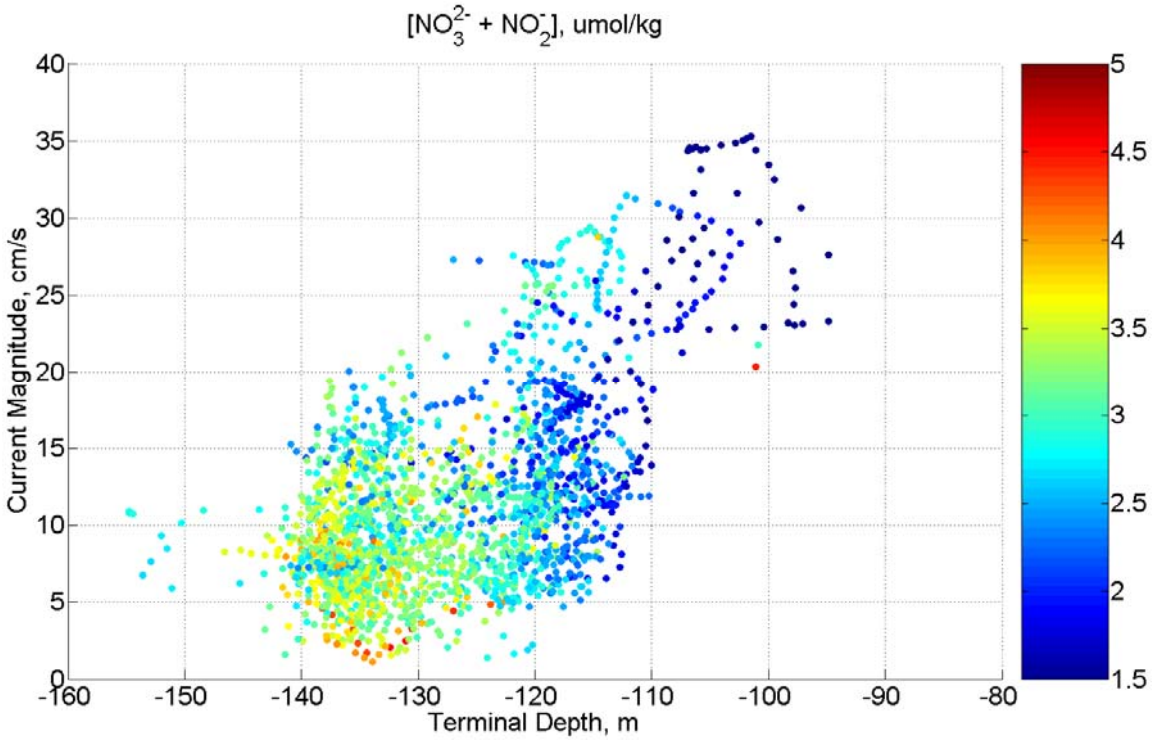


Figure 10 Scatter plot showing near-field plume terminal depth (equilibrium depth) and background current speeds (taken at 100m depth). Nitrate + nitrite concentrations (umol/kg) are shown in color. These results were taken from a simulation of a 10MW OTEC plant with 70m mixed discharge, a discharge diameter of 7.15m, and outlet velocity of 1 m/s. Total warm water flow was 40 m^3/s and cold water flow was 35 m^3/s.

Discussion:

Makai simulated a 10MW OTEC plant with 70 meter deep mixed discharges offshore Barbers Point, Oahu using a 20 day HIROM hindcast from September - October 2009. Results show that the plumes have a high dependence on the background currents, with significantly greater dilution and shallower plumes being formed under the presence of strong crossflows. The terminal depth of near-field plumes

varied from 100m to 160m with an average value of about 126m. The nitrate concentration of the near-field plumes at their terminal (equilibrium) depth averaged 2.9 umol/kg, showing a significant dilution of the cold water intake, which has 41 umol/kg of nitrate. This rapid dilution of the near-field plume, followed by additional far-field dilution, produces minimal perceivable impacts 440 meters away from the plant with regards to nutrient loading in the photic zone. The average nutrient content of the water around the OTEC plant remains within the naturally occurring variability of the HOT measurements, further highlighting the relatively small impact from operating a 10MW OTEC facility.

Makai's OTEC plume model may also be used to aid in future design decisions. As the scale and design limitations of the pilot plant change, so will the scale of the discharge plumes. Yet, it will be important to maintain a discharge that can be used to calibrate models and provide confidence in the ability to properly predict the fate of large scale OTEC plumes. Maintaining the densimetric Froude similitude (ratio of the plume's momentum to buoyant forces) is typically used to maintain the physics and similar mixing processes between prototype and model scales. If this Froude similitude is met, the numerical tools used to predict large scale OTEC plumes can be properly calibrated from measurements on the pilot plant. However, designing for an exact Froude similarity will likely be unfeasible, since it would require large discharge diameters. Makai's OTEC Plume Model can be used to study the effects of varying discharge configurations in order to provide an economically feasible scaling condition that will still provide a satisfactory similarity in the behavior and mixing processes of a full-scale 100MW plume.

References:

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Choi, K.W., Lee, J.H.W. (2007). Distributed Entrainment Sink Approach for Modeling Mixing and Transport in the Intermediate Field. *J. Hydraulic Eng.,* **133:7** 804.

Jensen, T. (1998) Open boundary conditions in stratified ocean models, *Journal of Marine Systems.,* **16** 297-322

Lavelle, J.W., Thacker, W.C. (2008) A pretty good sponge: Dealing with open boundaries in limited-area ocean models. *Ocean Modelling,* **20** 270-292.

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-13
Drawings
OTEC-2010-001

17 September 2010

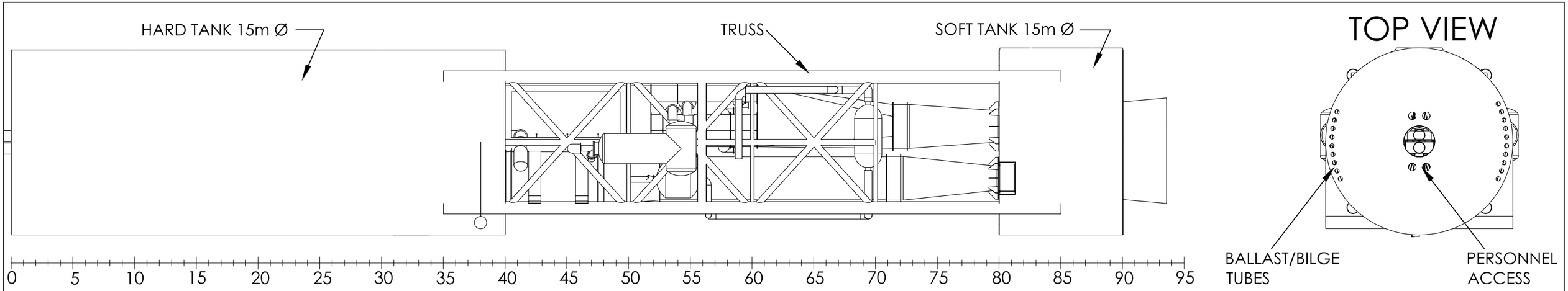
Prepared for:

Naval Facilities Engineering Command
Naval Facilities Engineering Service Center (NFESC)
1100 23rd Avenue
Port Hueneme, CA 93043-4370
Attn: Mr. Brian Cable, Contracting Officer Representative

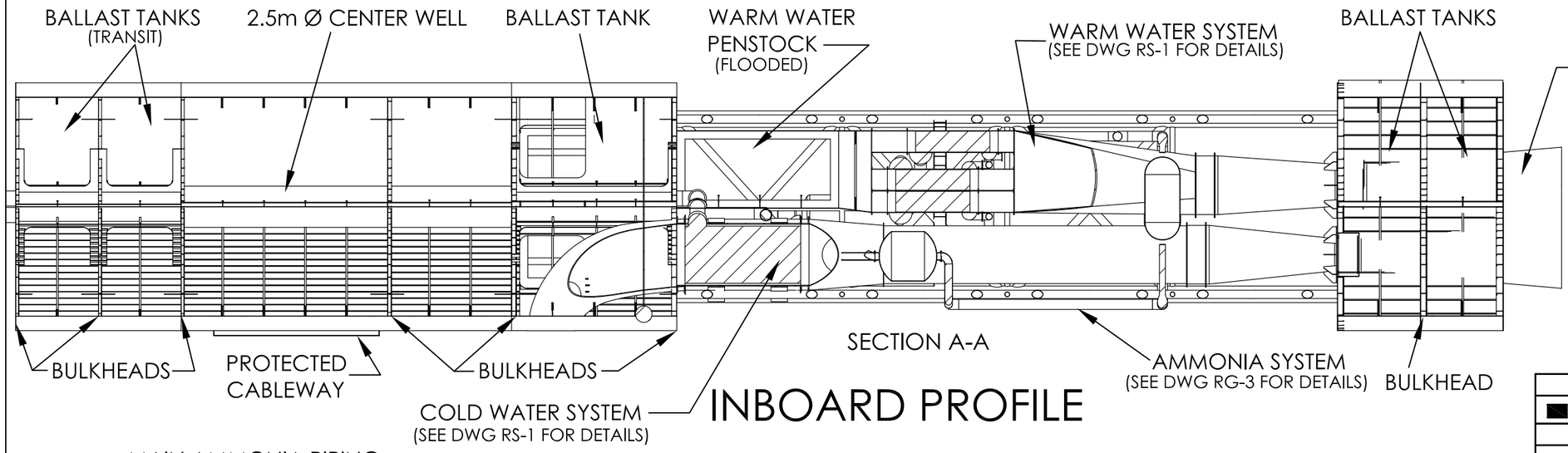
Prepared by:

Lockheed Martin MS2
9500 Godwin Drive
Manassas, VA 20110

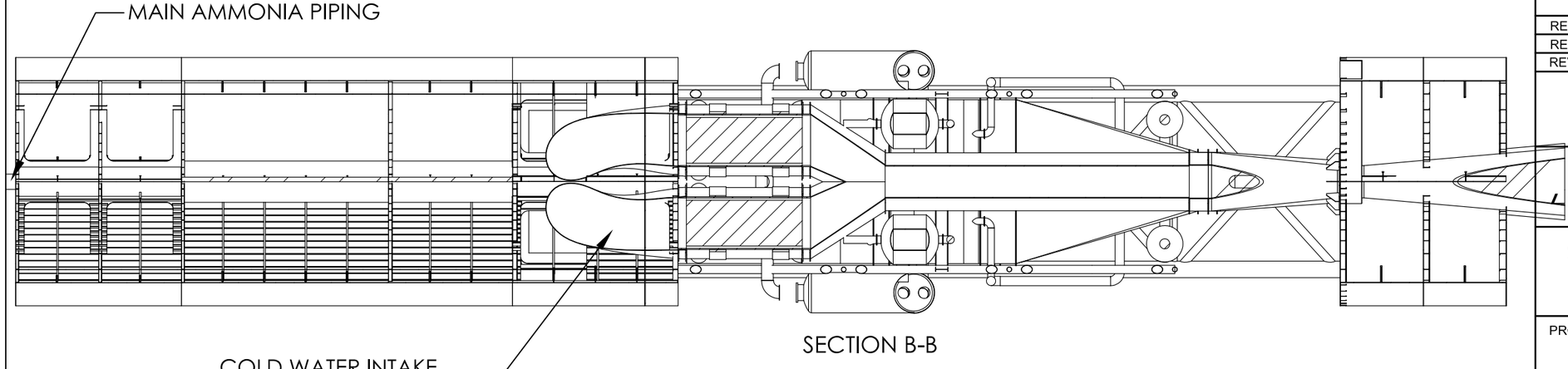
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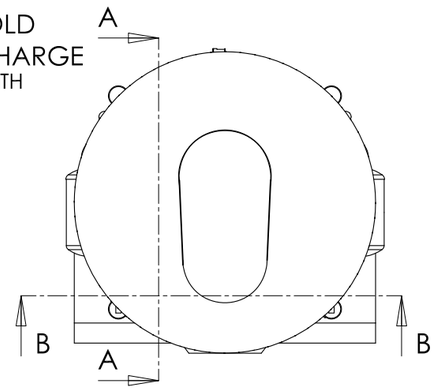


INBOARD PROFILE



COLD WATER ELEVATION

BOTTOM VIEW



TOP VIEW

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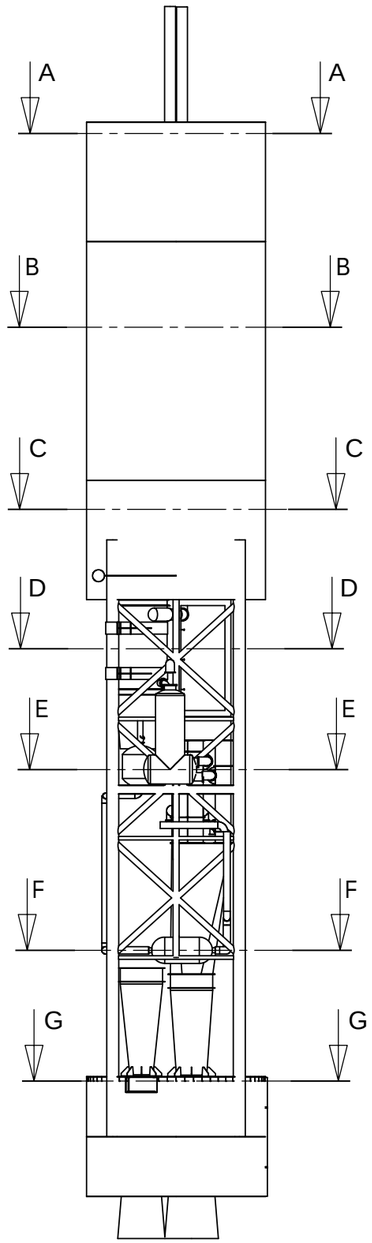
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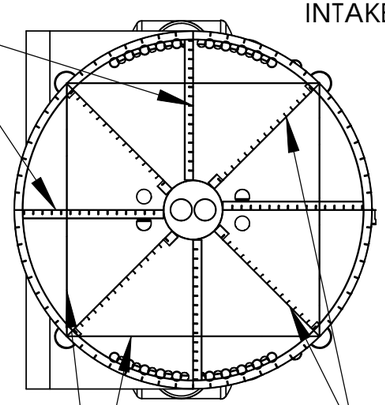
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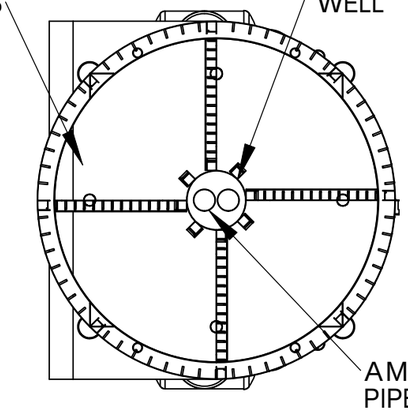
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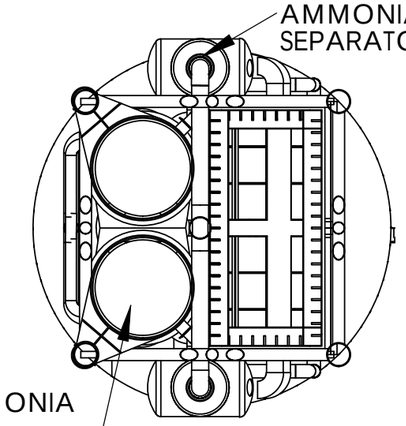
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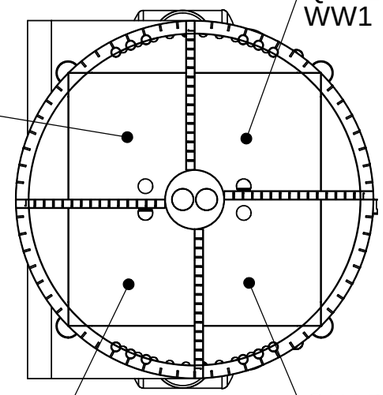
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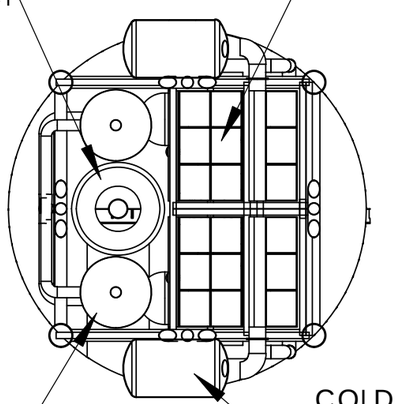
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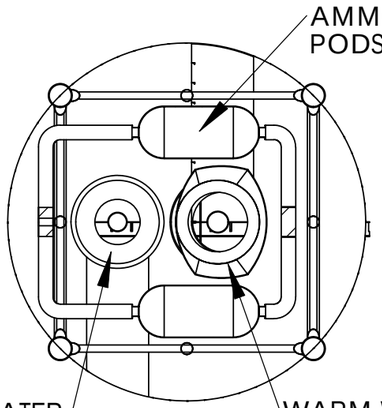
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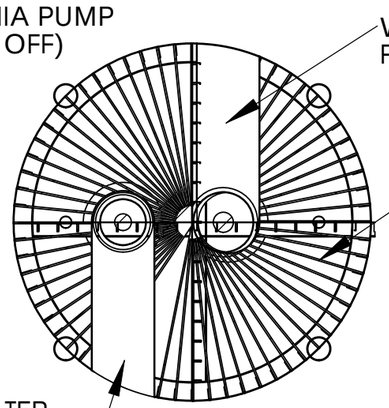
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SECTION E-E



SECTION F-F



SECTION G-G

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Manassas, VA 20110-4121

SCALE
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PROFILE 1:500

DWG NR
RG-2

PROJECT
NAVFAC OTEC PROJECT

SUBJECT
REMORA GA - SECTIONS

LEGEND

T TEMPERATURE METER	PUMP
P PRESSURE METER	TURBINE
F FLOWMETER	P PRESSURE GAUGE
M MASS FLOWMETER	HSRV HYDROSTATIC RELEASE VALVE
L LEVEL SENSOR	VAC VACUUM
CHECK VALVE	NC NORMALLY CLOSED
VALVE	TRB TURBINE
FLANGE	SEP SYS SEPARATION SYSTEM
	SCHED SCHEDULE

NH3 TANK A

NH3 TANK B

NH3 TANK C

NC

HSRV

ø4" SCHED 40

ø4" SCHED 40

HSRV

NC

NH3 TRANSFER PUMP

ø2" SCHED 20

TO AUTO PURGER

NC

ø2" SCHED 40

HSRV

HSRV

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$T_{TRB,OUT}$

$P_{TRB,IN}$

$T_{TRB,IN}$

THROTTLE/TRIP

ø2" SCHED 40

OIL SEP SYS

TURBINE–GENERATOR SKID

BYPASS VALVE

NC

LUBE OIL SKID

ø36" SCHED 20

ø36" SCHED 20

PLATFORM

REMORA

ø36" SCHED 40

ø36" SCHED 40

WATERLINE

ø2" SCHED 40

ø36" SCHED 40 (TYP)

COND 1

COND 2

ø4" SCHED 40 (TYP)

ø30" SCHED 40

P_{DEMIS}

P_{DEMIS}

DEMISTER VESSEL 1

DEMISTER VESSEL 2

EVAPORATOR (1 OF 6, TYP)

ø18" SCHED 40 (TYP)

ø18" SCHED 40 (TYP)

BUFFER TANK 1 AND 2

L_{DEMIS}

L_{DEMIS}

$P_{EVAP,OUT}$

ø18" SCHED 40

ø24" SCHED 40

$T_{EVAP,IN}$

$P_{EVAP,IN}$

NC

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ø18" SCHED 40

ø18" SCHED 40

ø18" SCHED 40

VAC

dP

STRAINER

NH3 FEED PUMP

ø18" SCHED 40

NH3 PUMP POD 1

VAC

dP

STRAINER

NH3 FEED PUMP

NH3 PUMP POD 2

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SCHEMATIC

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OCEAN ENGINEERING, INC.

LOCKHEED MARTIN
Lockheed Martin
9255 Wellington Road
Manassas, Va. 20110-4121

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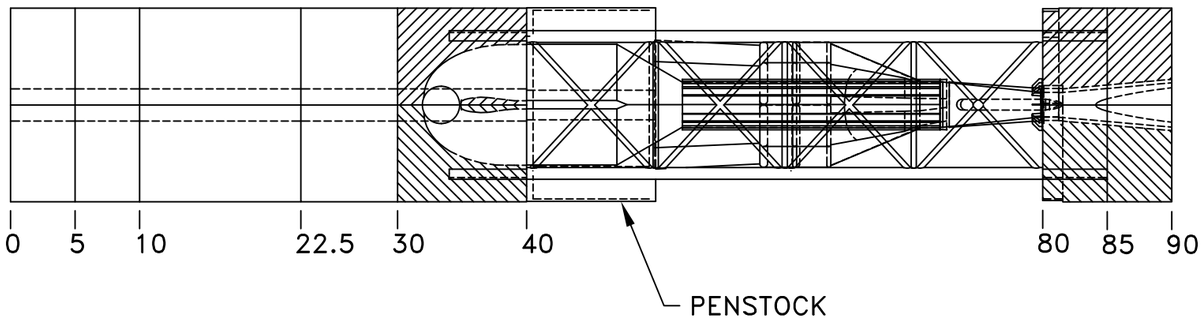
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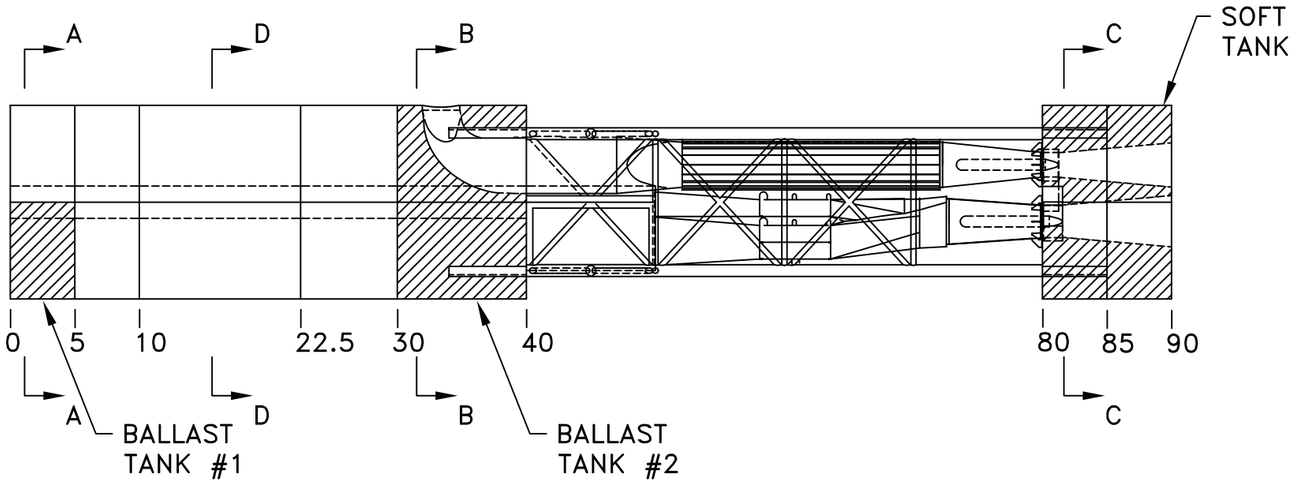
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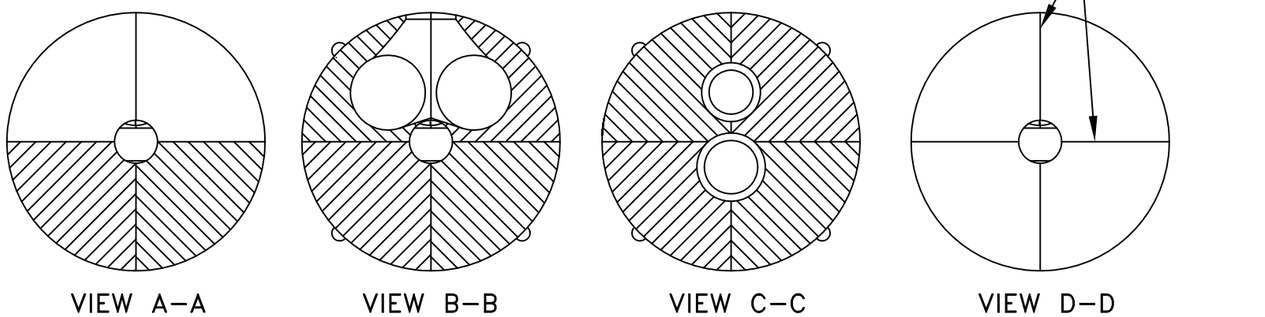
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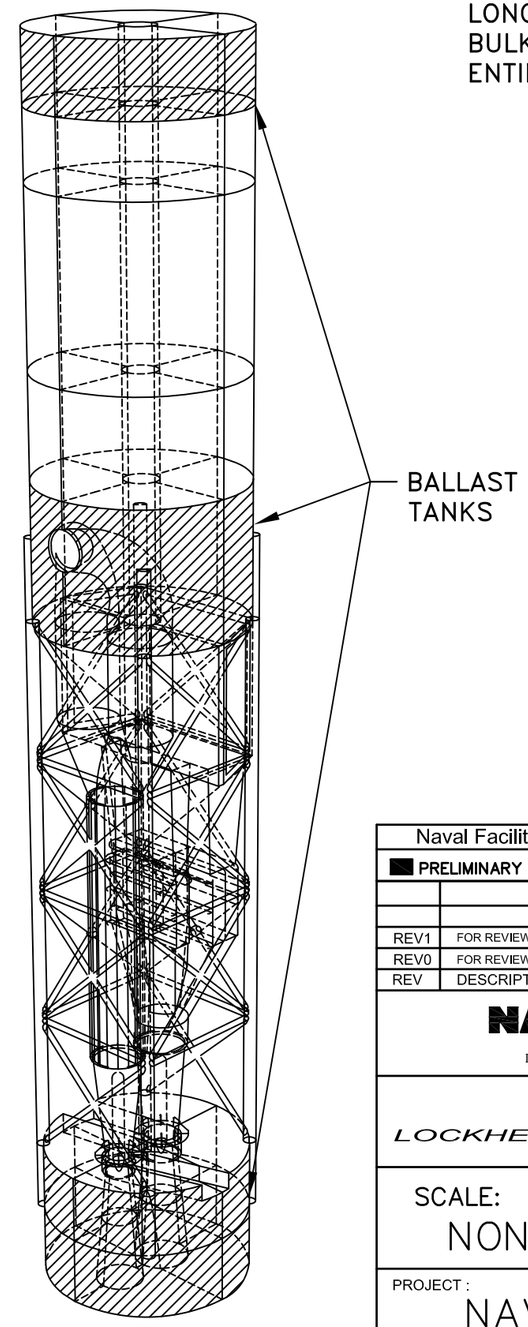
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REMORA BUOYANCY

NOTES:
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DIMENSIONS IN METERS
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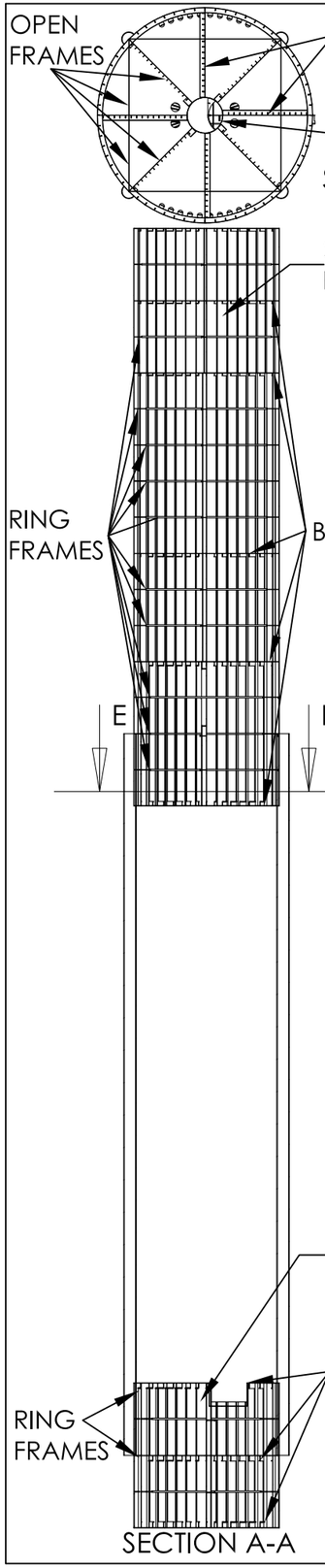
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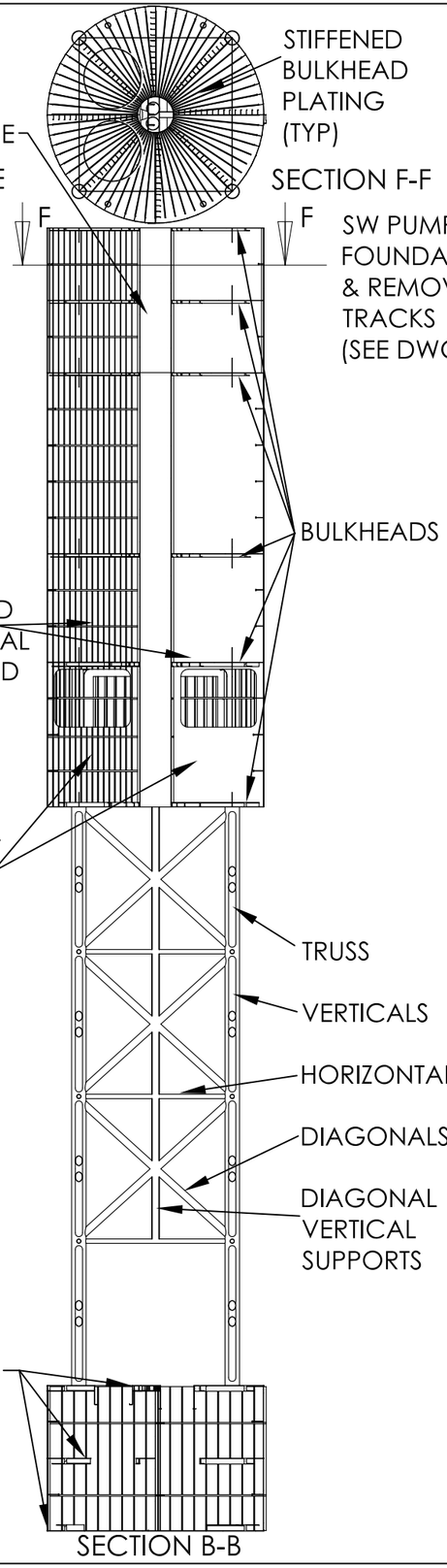
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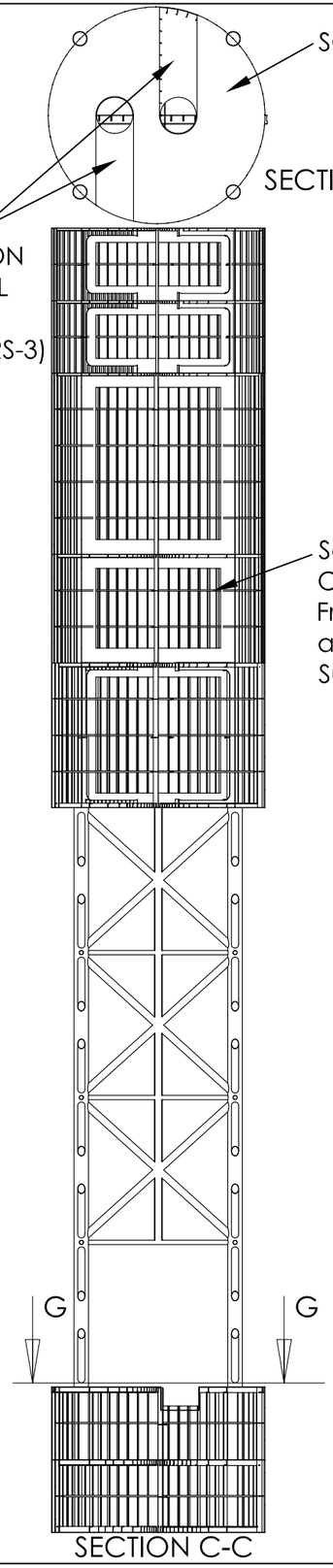
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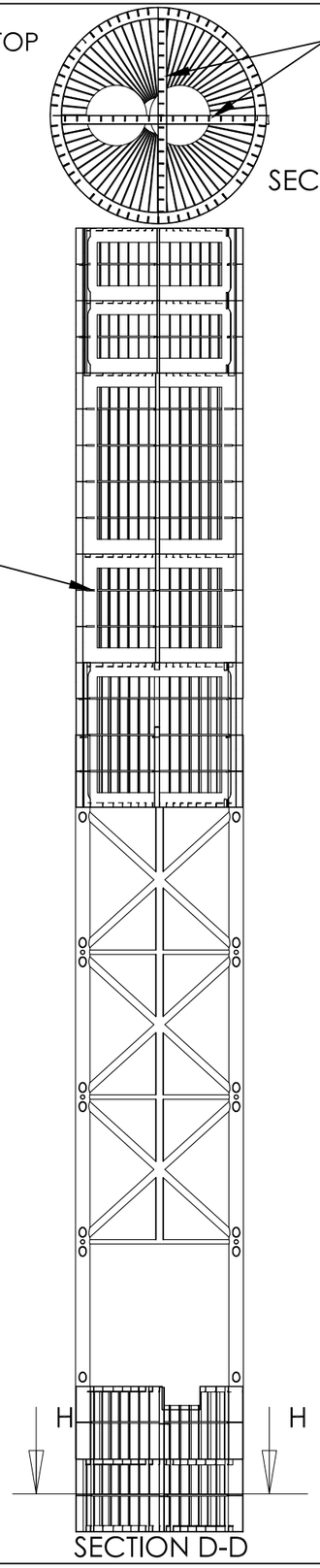
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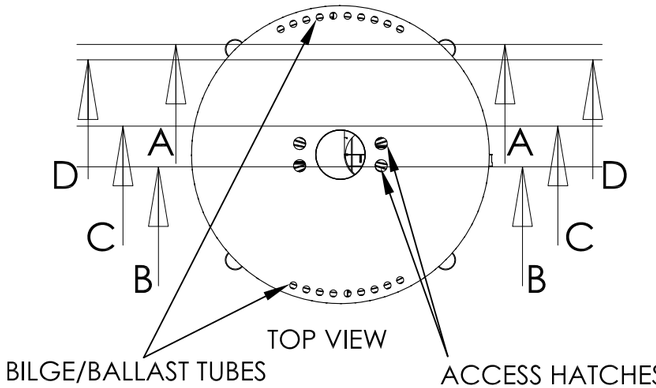
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DIMENSIONS IN METERS
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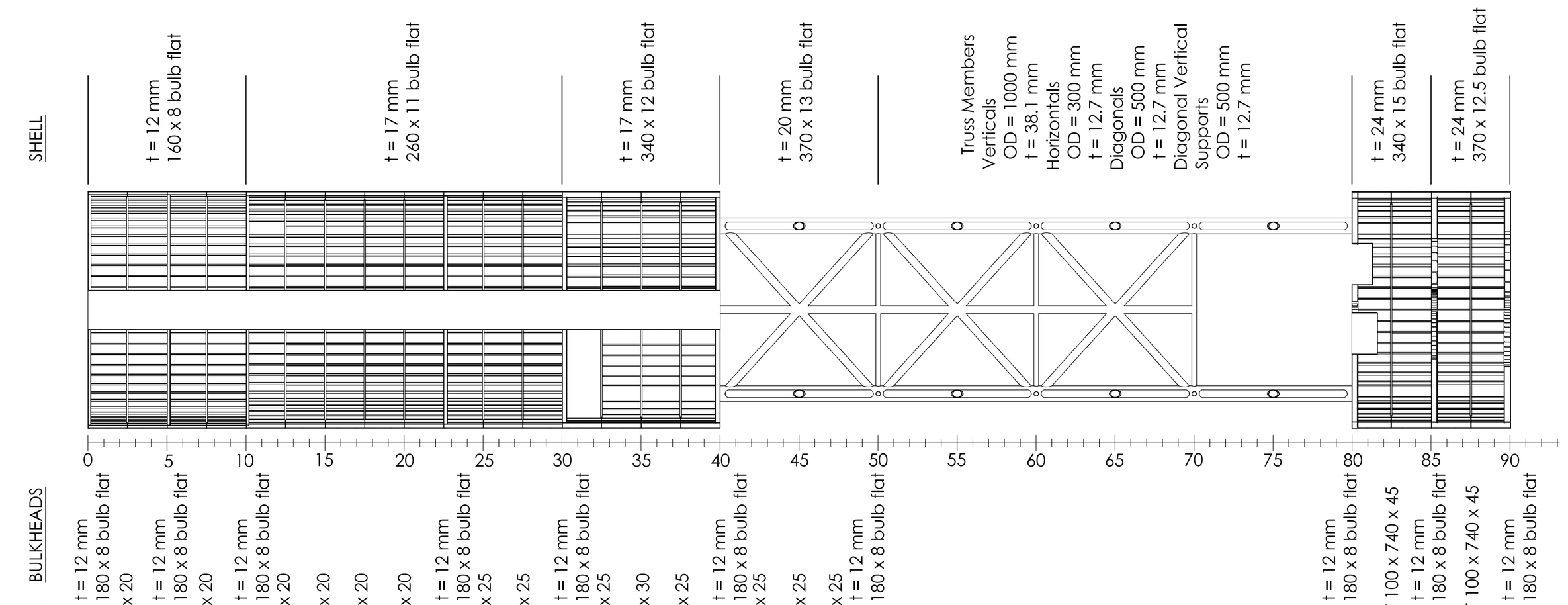
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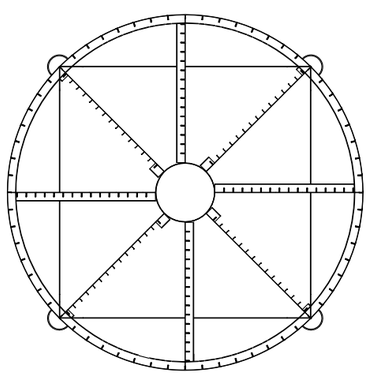
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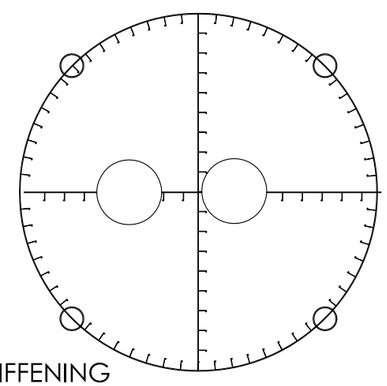
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UPPER HULL
CENTER TUBE
WT BULKHEADS
OPEN FRAMES
- MATCHES PLATE THICKNESS
- STIFFENING MATCHES PLATE STIFFENING



LOWER HULL
WT BULKHEADS
- MATCHES PLATE THICKNESS
- STIFFENING MATCHES PLATE STIFFENING

DIMENSIONS IN METERS

Conceptual Design

Naval Facilities Engineering Service Center, Port Hueneme CA

PRELIMINARY DWG ☐ CONTRACT DWG ☐ WORKING DWG ☐ AS BUILT

REV	DESCRIPTION	DATE	DRAWN	CHECK
REV1	FOR REVIEW	08/10/10	RSH	PG
REV0	FOR REVIEW	06/15/10	RSH	RSH

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SCALE: 1: 250

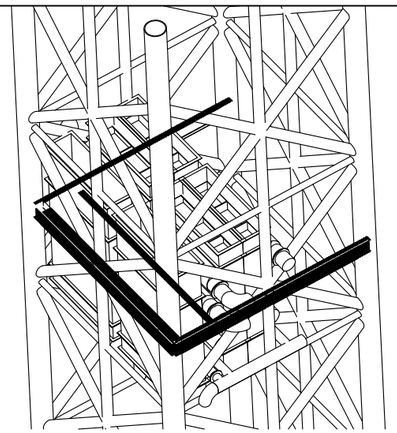
DWG. NR. RH–3

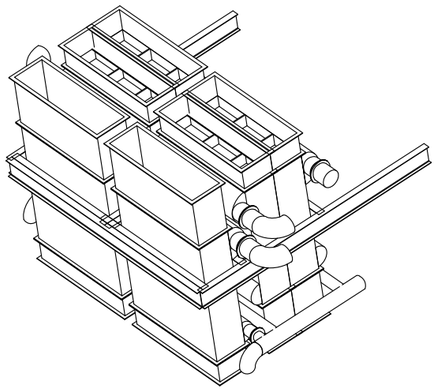
PROJECT : NAVFAC OTEC PROJECT

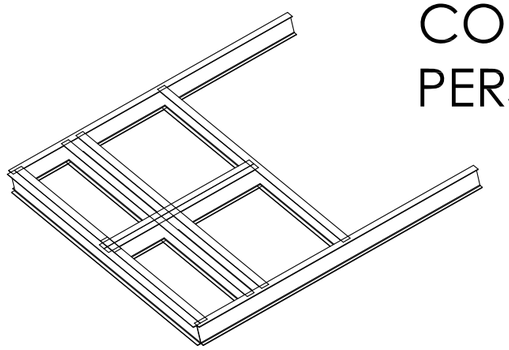
SUBJECT : REMORA STRUCTURAL SCANTLINGS

DATE: 10 AUG 2010

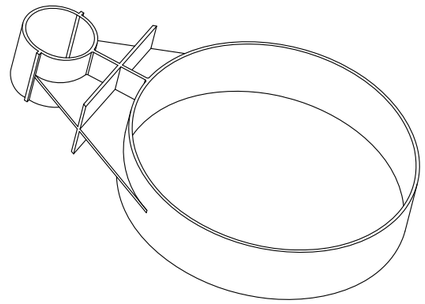
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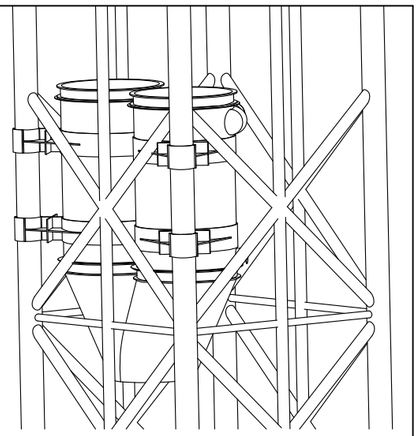




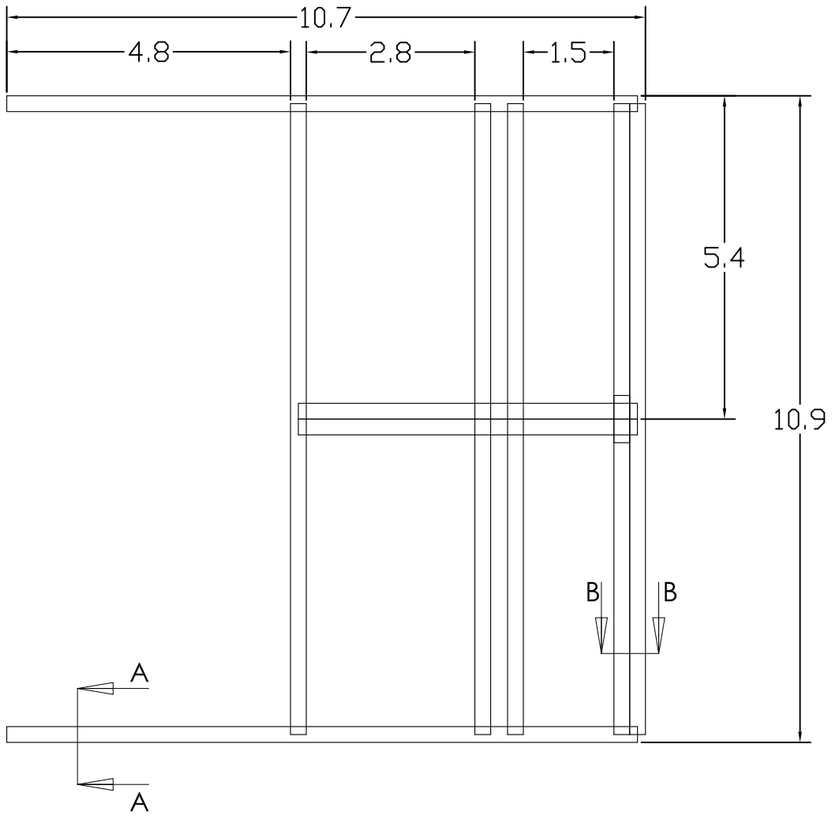


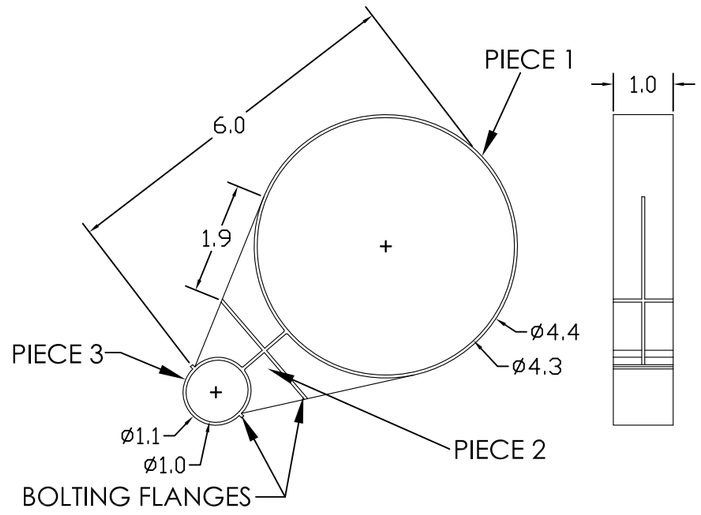
CONDENSER FOUNDATION PERSPECTIVES

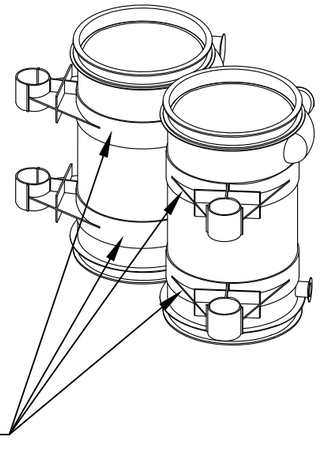




EVAPORATOR FOUNDATION PERSPECTIVES



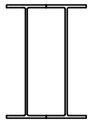




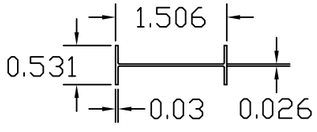
CONDENSER FOUNDATION

EVAPORATOR FOUNDATION

TWO STD SIZE BEAMS NEXT TO EACH OTHER



SECTION B-B



SECTION A-A

ALL BEAMS IN EVAPORATOR FOUNDATIONS ARE W30 x 99 I BEAMS. BEAM DIMENSIONS SHOWN IN SECTION A-A

DIMENSIONS IN METERS
Conceptual Design

Naval Facilities Engineering Service Center, Port Hueneme CA

■ PRELIMINARY DWG ☐ CONTRACT DWG ☐ WORKING DWG ☐ AS BUILT

REV	DESCRIPTION	DATE	DRAWN	CHECK
REV1	FOR REVIEW	08/13/10	RSH	PG
REV0	FOR REVIEW	07/21/10	RSH	PG

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SCALE: 1:100

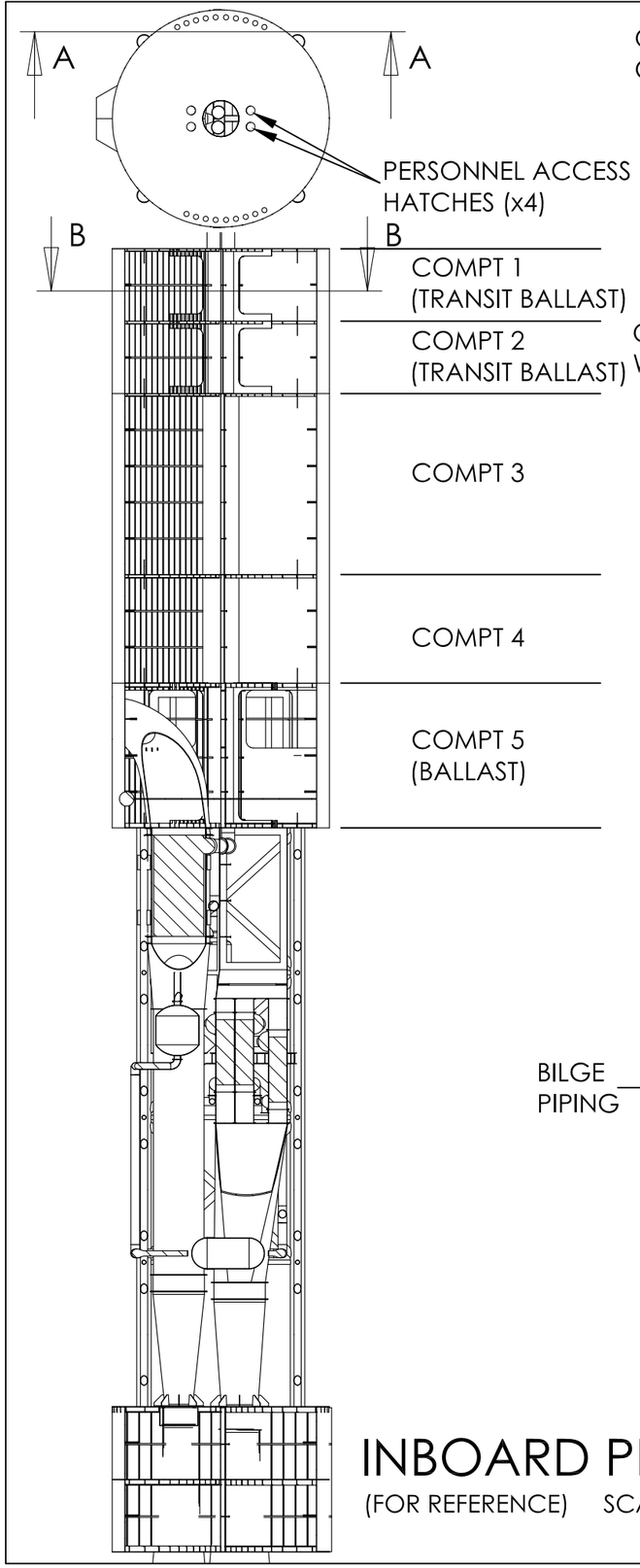
DWG. NR. RH-4

PROJECT : NAVFAC OTEC PROJECT

SUBJECT : HEAT EXCHANGER FOUNDATIONS

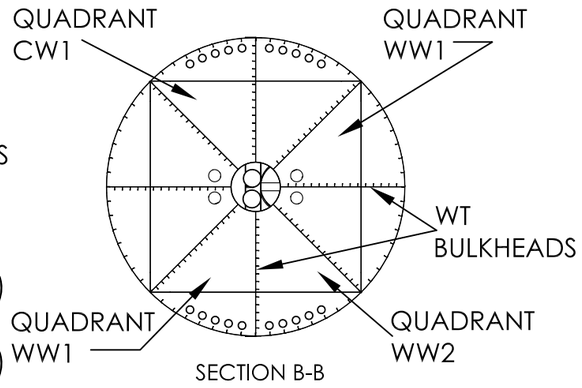
FILE: RH4HXMOUNTINGDETAIL100813

DATE: 13 AUG 2010

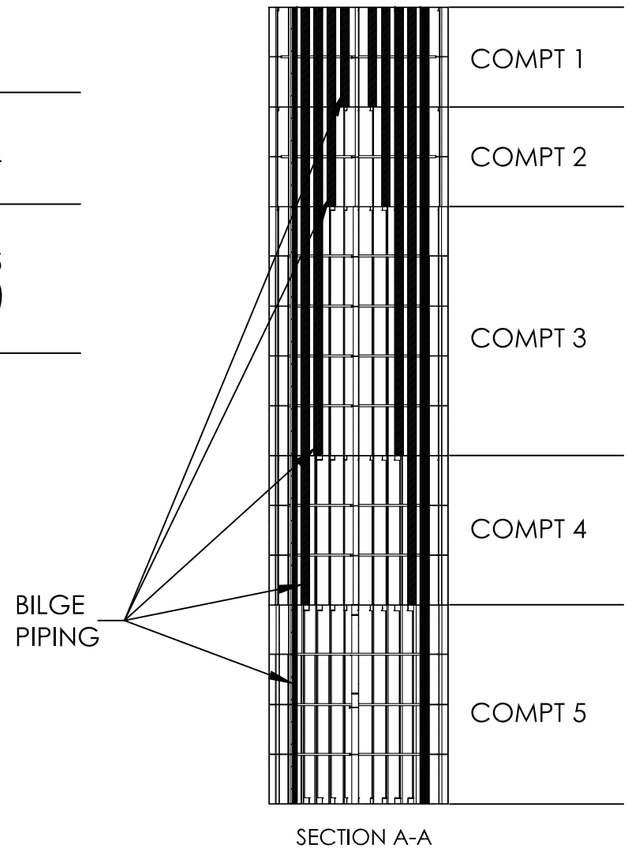


INBOARD PROFILE

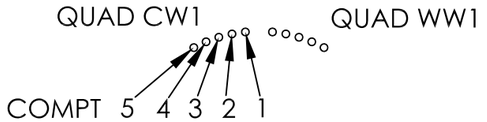
(FOR REFERENCE) SCALE 1:400



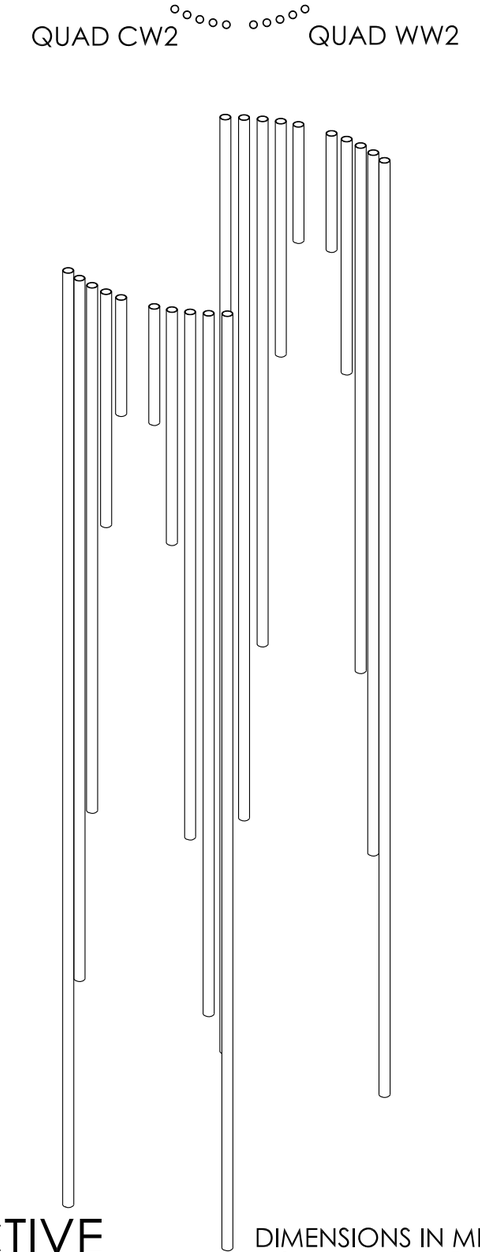
SECTION B-B



SECTION A-A



PIPING ARRGT SIMILAR FOR EACH QUADRANT



PERSPECTIVE

DIMENSIONS IN METERS
Conceptual Design

NOTES:

1. BALLAST TUBES SEALED ON HARD TANK TOP LEVEL WITH WT SCREW-ON CAP

2. BALLAST AND BILGE SYSTEMS SHARE BILGE PUMPS AND TUBES

3. REMORA ONLY DESIGNED FOR RARE PERSONNEL ACCESS

4. PERSONNEL ACCESS HOLES COVERED ON HARD TANK TOP LEVEL WITH WT FREEMAN-TYPE HATCH

BILGE/BALLAST PROCEDURE

A. TWO PORTABLE BALLAST PUMPS STOWED ON PLATFORM

B. ALL WT COMPARTMENTS EQUIPPED WITH AUTOMATIC HIGH BILGE LEVEL ALARM

C. AFTER ALARM ACTIVATION, IDENTIFY FLOODED WT COMPARTMENT

D. REMOVE BILGE TUBE COVER

E. LOWER BILGE PUMP INTO COMPARTMENT

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■ PRELIMINARY DWG ☐ CONTRACT DWG ☐ WORKING DWG ☐ AS BUILT

REV	DESCRIPTION	DATE	DRAWN	CHECK
REV1	FOR REVIEW	08/10/10	RSH	PG
REV0	FOR REVIEW	06/15/10	RSH	RSH

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SCALE: 1:200

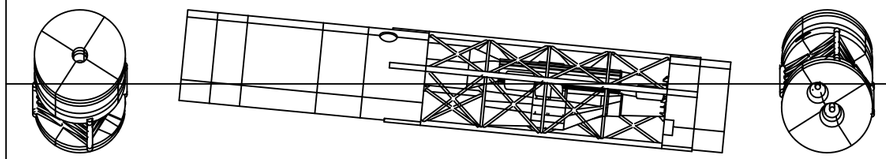
DWG. NR. RH–5

PROJECT : NAVFAC OTEC PROJECT

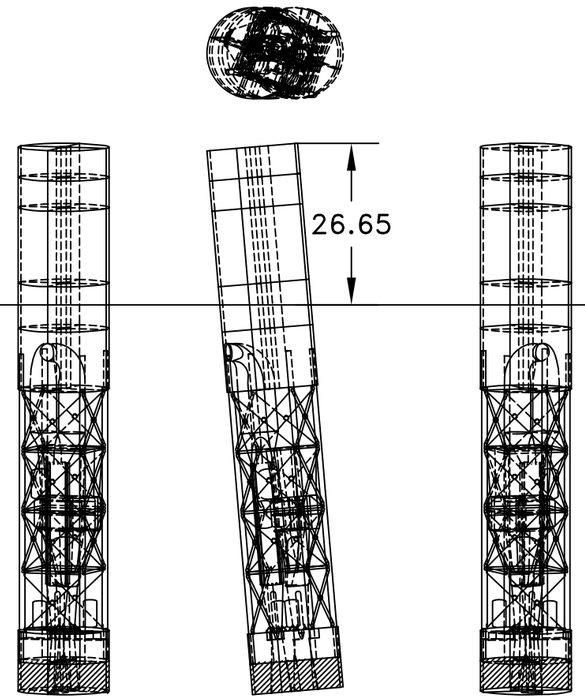
SUBJECT : REMORA BILGE/BALLAST SYSTEMS

FILE: RH5AUXSYSTEMSV3100810

DATE: 10 AUG 2010



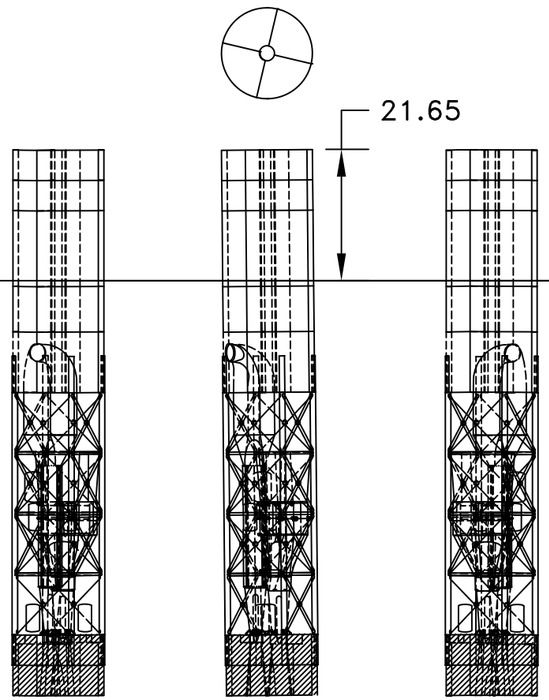
TOW CONFIGURATION



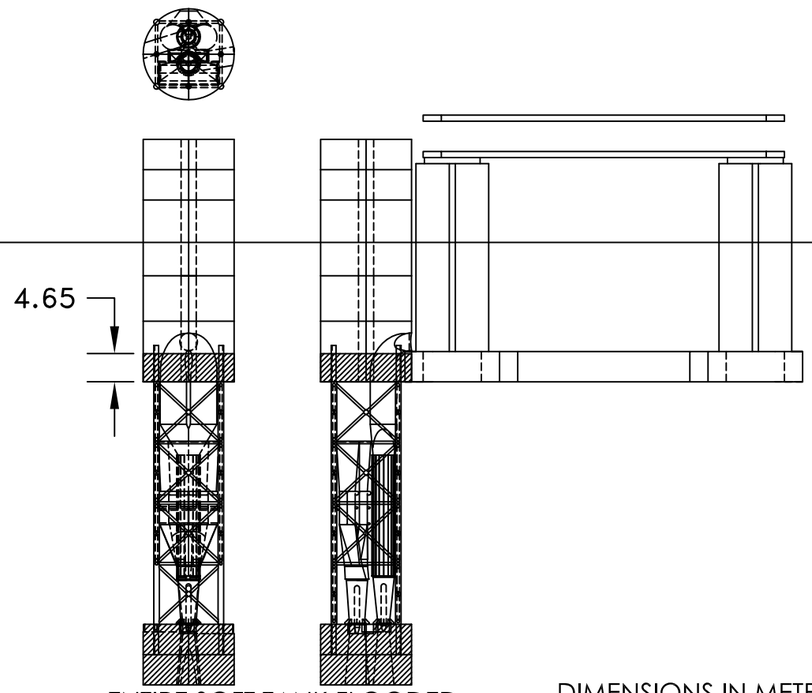
LOWER 5m OF SOFT TANK FLOODED

UPENDING PROCEDURE:

1. ATTACH TAG LINE TO SUPPORT VESSEL
2. FLOOD 10m SOFT TANK



ENTIRE SOFT TANK FLOODED



ENTIRE SOFT TANK FLOODED
LOWER BALLAST TANK FILLED 4.65m

DIMENSIONS IN METERS
Conceptual Design

WEIGHT = 3358295 KG
VCG= -48.272m, VCB = -26.5m

Naval Facilities Engineering Service Center, Port Hueneme CA

■ PRELIMINARY DWG ☐ CONTRACT DWG ☐ WORKING DWG ☐ AS BUILT

REV	DESCRIPTION	DATE	DRAWN	CHECK
REV1	FOR REVIEW	08/17/10	RSH	PG
REV0	FOR REVIEW	06/16/10	SJS	PG

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SCALE: NONE

DWG. NR. RH-6

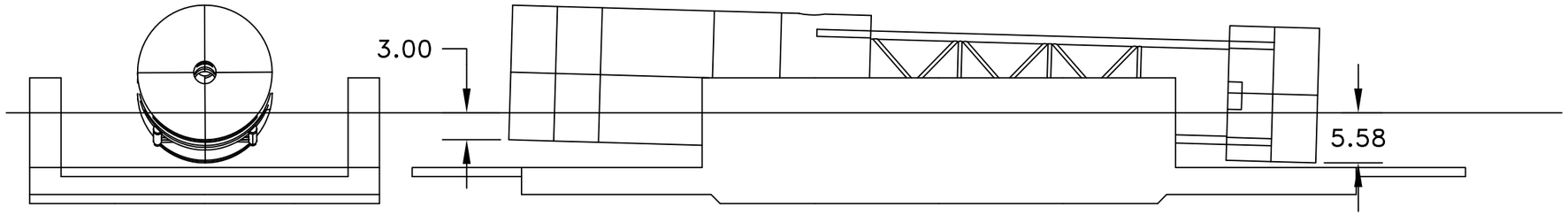
PROJECT : NAVFAC OTEC PROJECT

SUBJECT : UPENDING CONOP

FILE: RH6UPENDINGCONOPV3100817

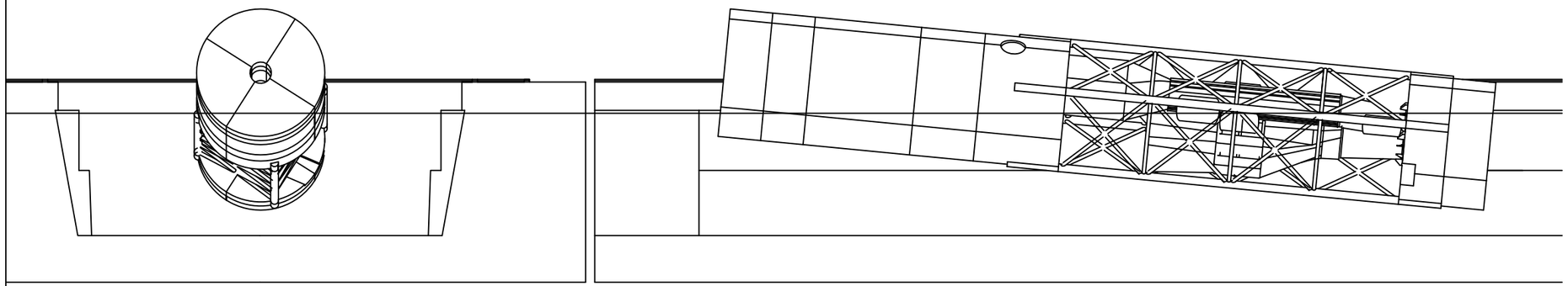
DATE: 17 AUG 2010

OPTION 1: DOCKING



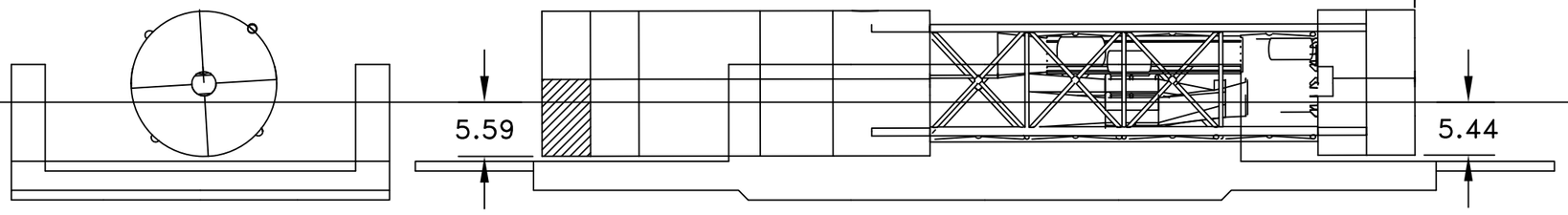
PSI DRY DOCK-STRUCTURE ONLY

WEIGHT = 1976000 KG
LCG= 41.2m, VCG = 7.1m



PEARL HARBOR DRY DOCK #4

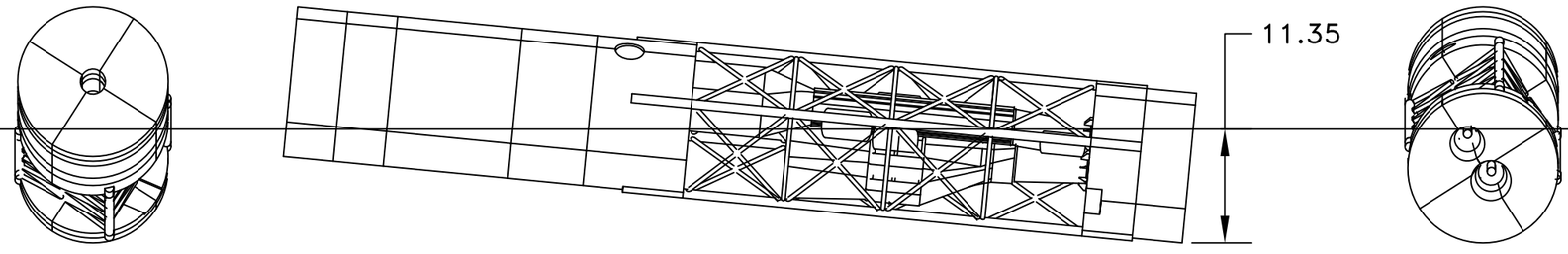
OPTION 2: DOCKING



PSI DRY DOCK-FULL LOAD

WEIGHT = 3114587 KG
LCG= 33.14m, VCG = 7.0m

TOW CONFIGURATION:



WEIGHT = 3358295 KG
LCG= 48.272m, VCG = 7.5m

DIMENSIONS IN METERS
Conceptual Design

TWO OPTIONS FOR DOCKING & UNDOCKING THE REMORA:
OPTION1: PSI DRY DOCK
OPTION 2: PEARL HARBOR DRYDOCK.
THE CURRENT PSI DRY DOCK REQUIRES FROM A FLOATING LIFT TO SUPPORT A FULL-LOAD REMORA. IT DOES HAVE THE DRAFT CAPACITY TO SUPPORT REMORA MODULES OR A 90M REMORA STRUCTURE ONLY.

DOCKING/UNDOCKING PROCEDURE
OPTION 1:
1. REMORA STRUCTURE ONLY, NO CW/WW OR AMMONIA SYSTEMS INSTALLED.
2. FLOAT OUT AND TOW TO PEARL HARBOR DRY DOCK #4.
3. FINAL INTEGRATION OF CW/WW AND AMMONIA SYSTEMS.

OPTION 2:
1. FLOATING CRANE WITH 700MT CAPACITY REQUIRED.
2. FILL BALLAST TANK #1.
3. POSITION FLOATING CRANE NEAR REMORA AND LIFT 666MT.
4. FLOAT OUT OF DRYDOCK.

TOWING PROCEDURE:
1. NO BALLAST TANKS FLOODED
2. TOW AT 3-4 KNOTS

Naval Facilities Engineering Service Center, Port Hueneme CA

■ PRELIMINARY DWG ☐ CONTRACT DWG ☐ WORKING DWG ☐ AS BUILT

REV	DESCRIPTION	DATE	DRAWN	CHECK
REV1	FOR REVIEW	08/17/10	RSH	PG
REV0	FOR REVIEW	06/15/10	SJS	PG

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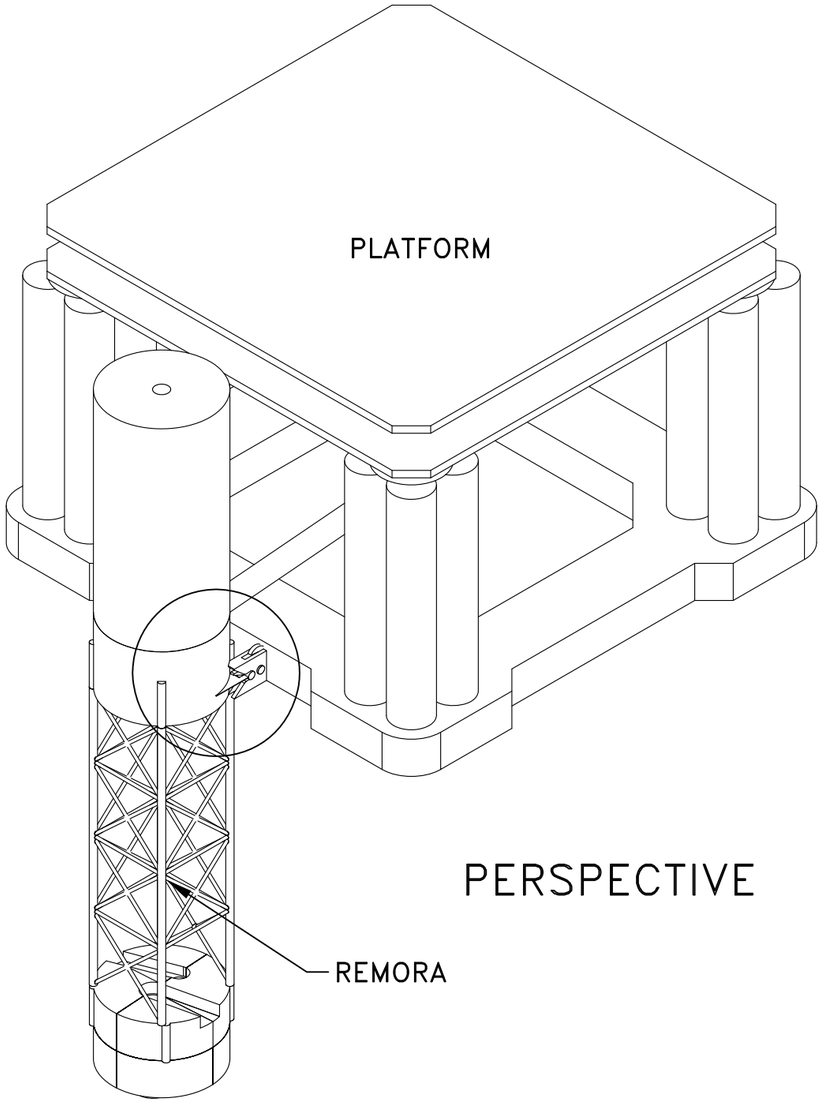
DWG. NR. RH-7

PROJECT : NAVFAC OTEC PROJECT

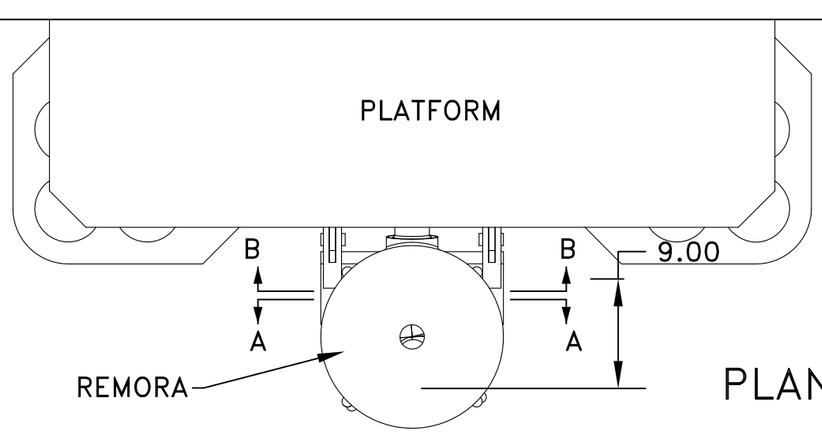
SUBJECT : TOWING & DOCKING CONOP

FILE: RH7TOWING&DOCKINGCONOPV3100817

DATE: 17 AUG 2010



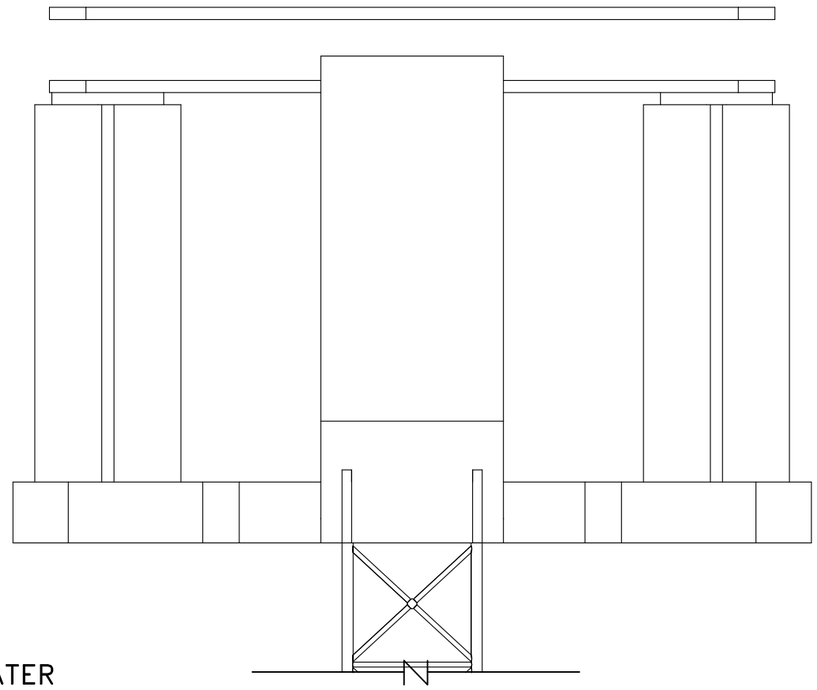
PERSPECTIVE



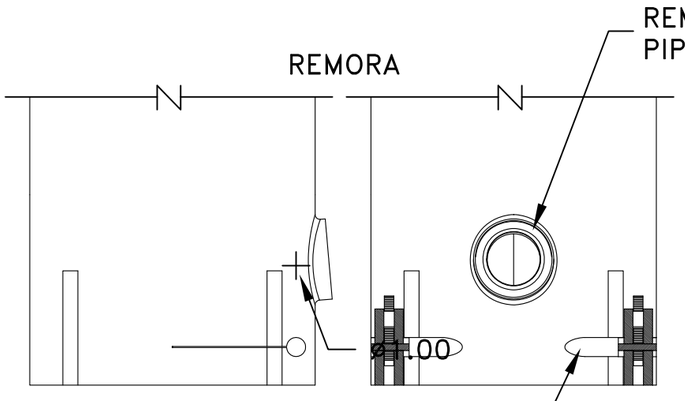
PLAN VIEW

NOTES:
1. REMORA CONNECTION ALLOWS FOR SIMULTANEOUS MATING OF REMORA TO PLATFORM AND COLD WATER (CW) PIPE CONNECTION TO REMORA CW INTAKE.

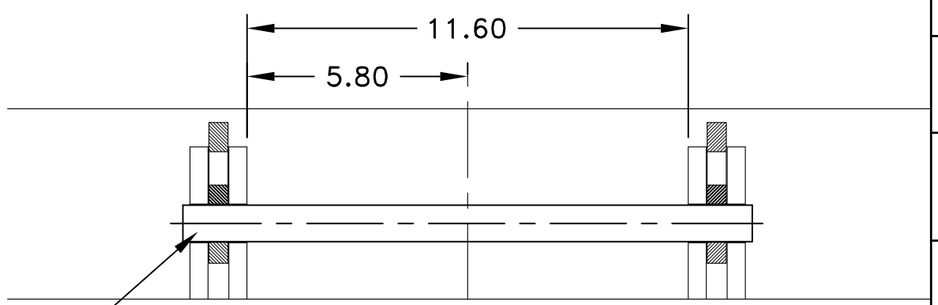
SEE DWG RH-9 FOR MOUNTING BRACKET DETAILS



PROFILE VIEW



SECTION A-A



SECTION B-B

DIMENSIONS IN METERS
Conceptual Design

Naval Facilities Engineering Service Center, Port Hueneme CA

■ PRELIMINARY DWG ☐ CONTRACT DWG ☐ WORKING DWG ☐ AS BUILT

REV	DESCRIPTION	DATE	DRAWN	CHECK
REV1	FOR REVIEW	08/17/10	RSH	PG
REV0	FOR REVIEW	06/15/10	SJS	PG

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SCALE: NONE

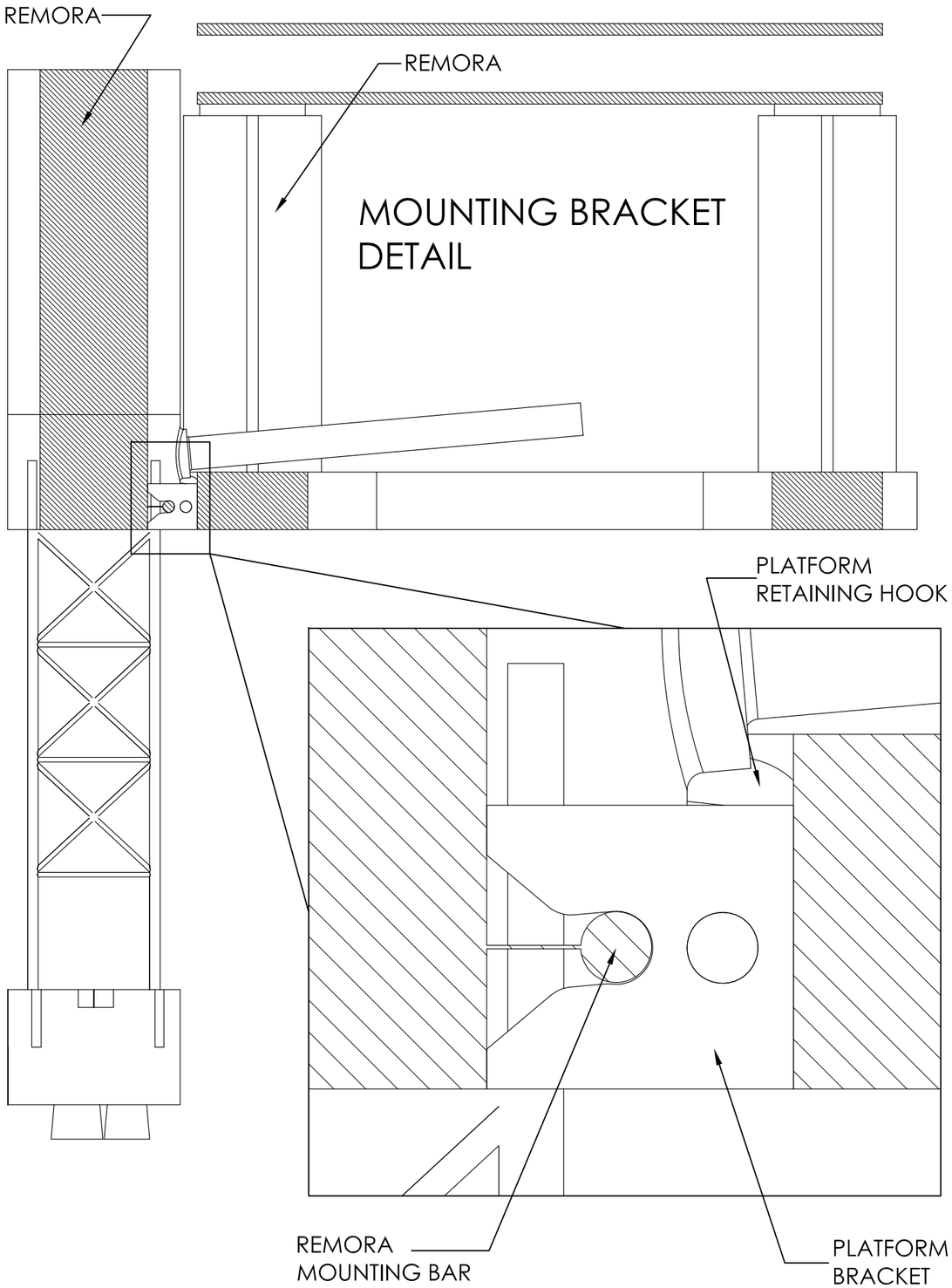
DWG. NR. RH-8

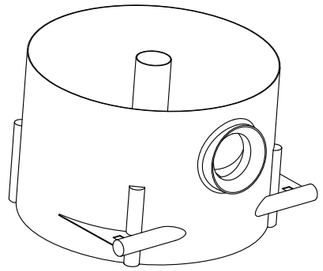
PROJECT : NAVFAC OTEC PROJECT

SUBJECT : MATING DEMATING CONOP

DATE: 17 AUG 2010

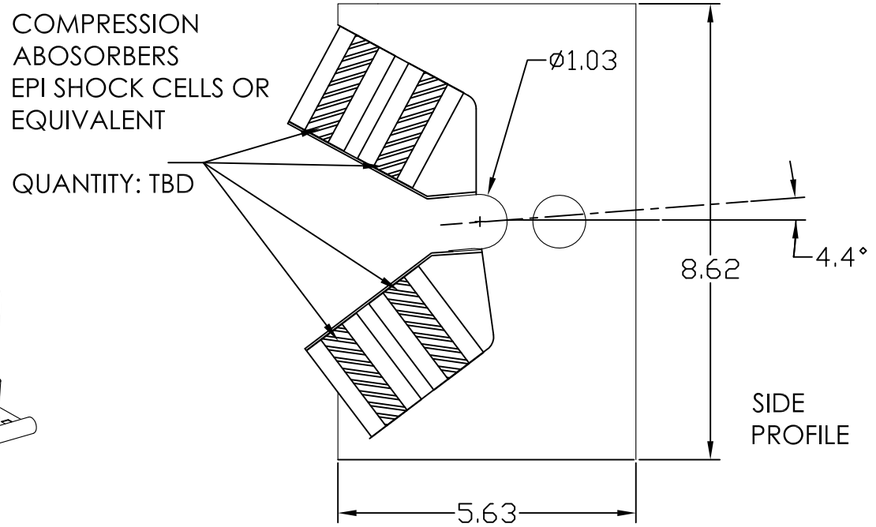
FILE: RHMATINGSDEMATINGSCONOPV3100817





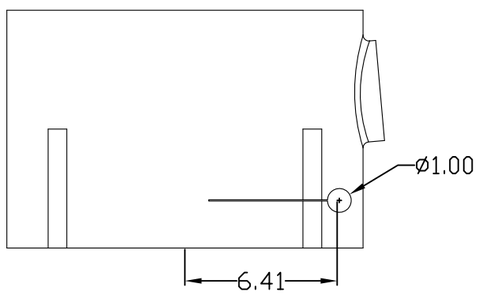
PERSPECTIVE

REMORA MOUNTING BAR

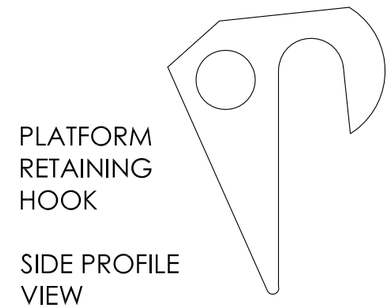


PLATFORM BRACKET

FRONT PROFILE



SIDE PROFILE



PLATFORM
RETAINING
HOOK

SIDE PROFILE
VIEW

DIMENSIONS IN METERS
Conceptual Design

Naval Facilities Engineering Service Center, Port Hueneme CA

■ PRELIMINARY DWG ☐ CONTRACT DWG ☐ WORKING DWG ☐ AS BUILT

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SCALE:
MOUNTING BAR 1:250
MOUNTING BRACKET 1:100

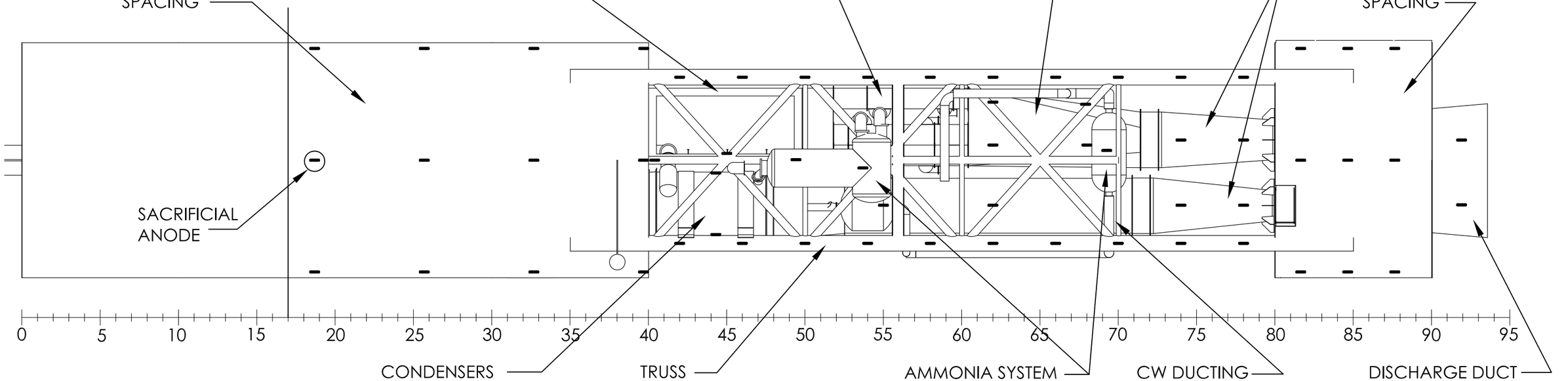
DWG. NR.
RH–9

PROJECT :
NAVFAC OTEC PROJECT

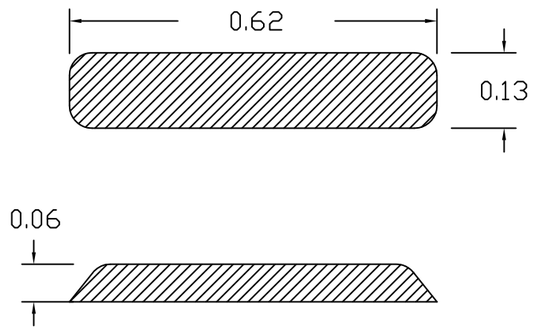
SUBJECT :
PLATFORM / REMORA MOUNTING BRACKET

FILE: RH9PLATFORMBRACKETV1100816

DATE: 17 AUG 2010



ALUMINUM HULL ANODES
GALVOTEC GA-A-1-29H SHOWN
113 ANODES TOTAL
13.1 kg PER ANODE



ANODE DETAIL SCALE 1:10

DIMENSIONS IN METERS
Conceptual Design

Naval Facilities Engineering Service Center, Port Hueneme CA

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Manassas, Va. 20110-4121

SCALE: 1:250

DWG. NR. RH-10

PROJECT : NAVFAC OTEC PROJECT

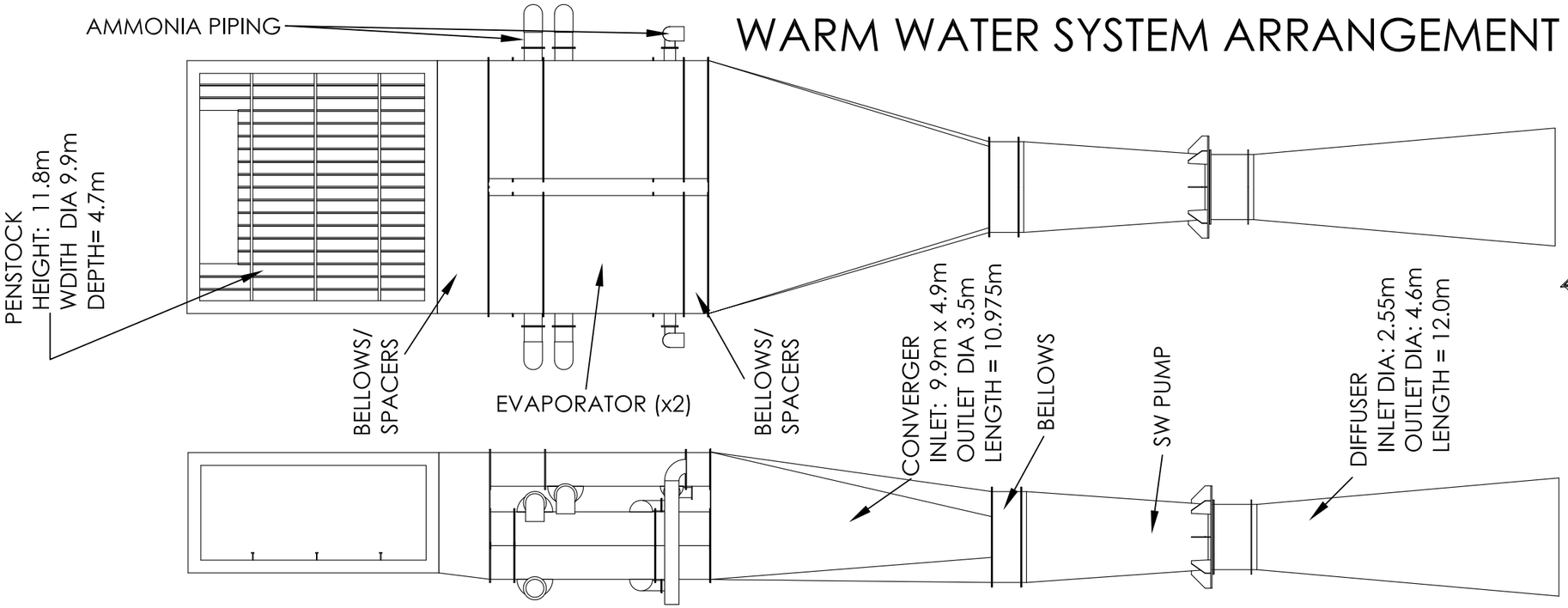
SUBJECT : REMORA CORROSION PROTECTION PLA

FILE: RH10CORROSIONPROTV3100811

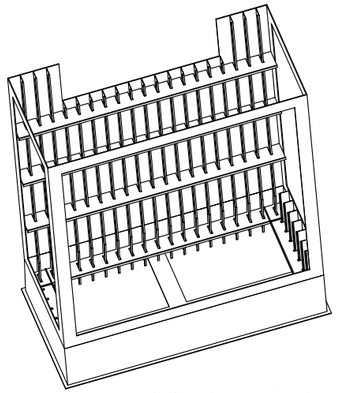
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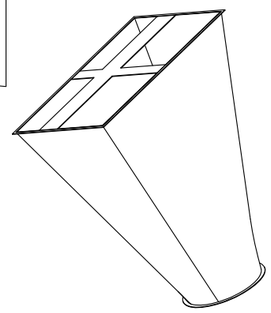
DATE: 11 AUG 2010

WARM WATER SYSTEM ARRANGEMENT



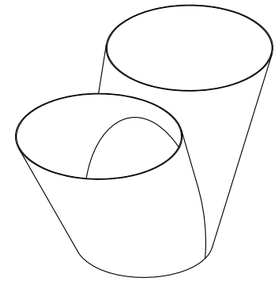
WARM WATER PENSTOCK (PERSPECTIVE)

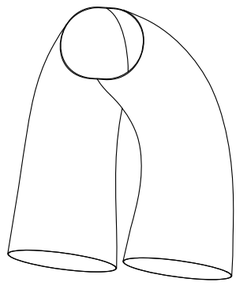




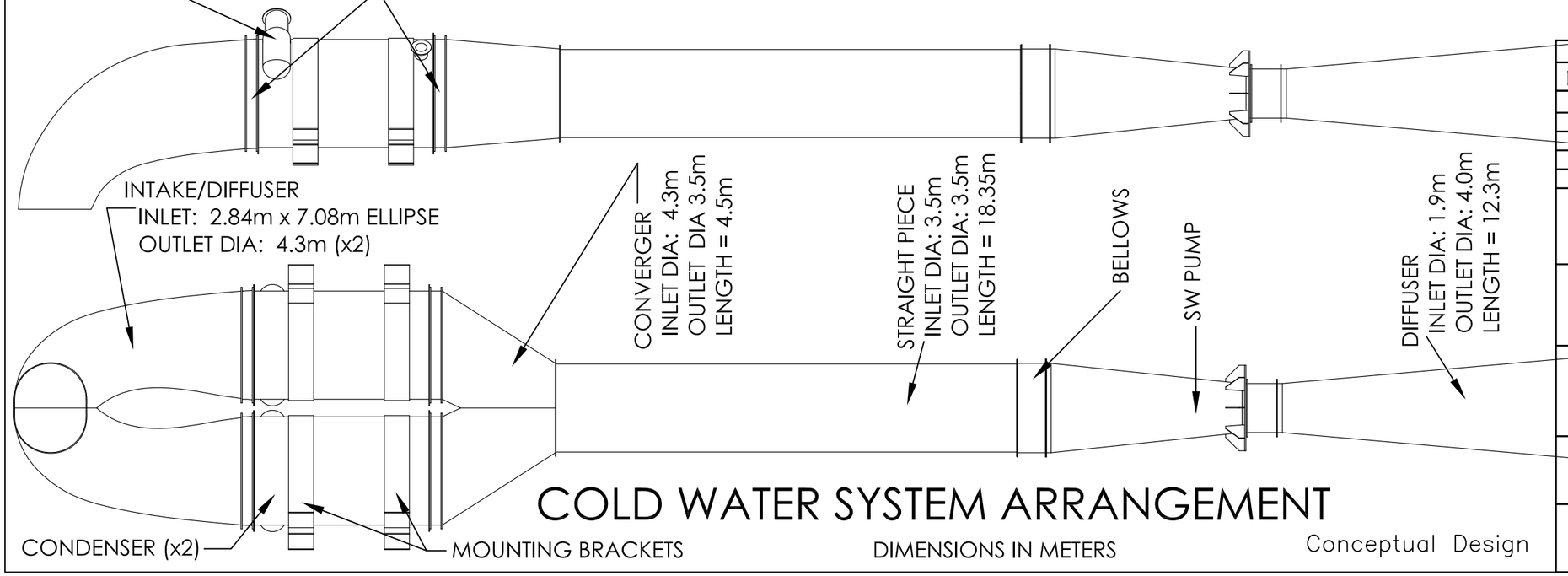
COLD WATER CONVERGER (PERSPECTIVE)

WARM WATER CONVERGER (PERSPECTIVE)





COLD WATER INLET (PERSPECTIVE)



COLD WATER SYSTEM ARRANGEMENT

DIMENSIONS IN METERS

Conceptual Design

Naval Facilities Engineering Service Center, Port Hueneme CA

■ PRELIMINARY DWG ☐ CONTRACT DWG ☐ WORKING DWG ☐ AS BUILT

REV	DESCRIPTION	DATE	DRAWN	CHECK
REV1	FOR REVIEW	08/12/10	RSH	PG
REV0	FOR REVIEW	06/15/10	RSH	RSH

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Design & Construction
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Phone: (808) 531 7001
Fax: (808) 523 7688

LOCKHEED MARTIN
Lockheed Martin
9255 Wellington Road
Manassas, Va. 20110-4121

SCALE: 1:200

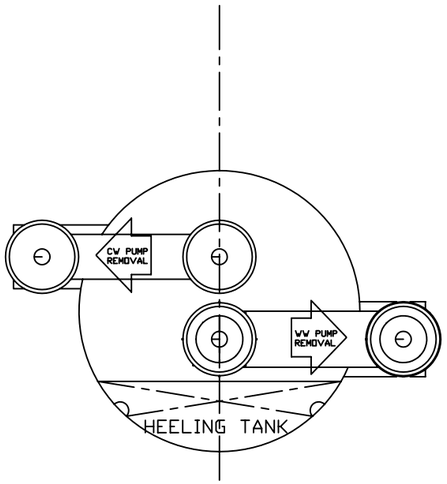
DWG. NR. RS–1

PROJECT: NAVFAC OTEC PROJECT

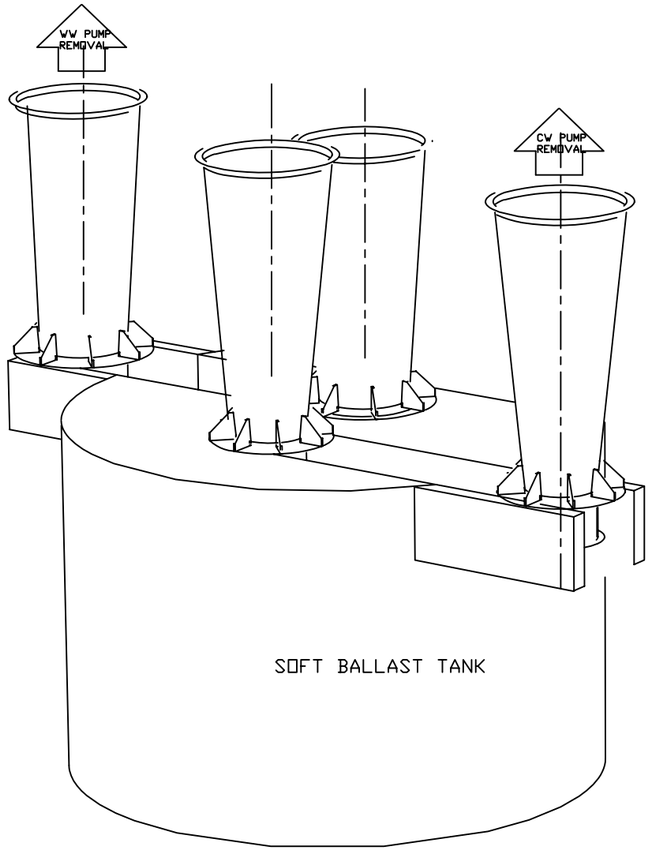
SUBJECT: REMORA SEAWATER DUCT ARRANGEMENTS

FILE: RS1SWDUCTARRGTV3100812

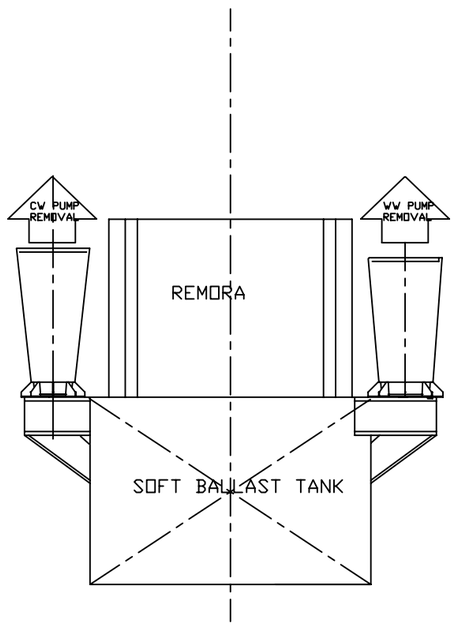
DATE: 12 AUG 2010



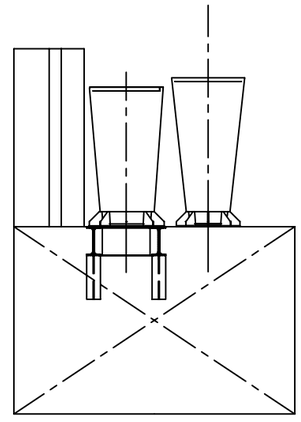
COLD WATER AND WARM WATER
PUMPS REMOVAL. PLAN



SOFT BALLAST TANK



COLD WATER AND WARM WATER
PUMPS REMOVAL. ELEVATION



COLD WATER AND WARM WATER
PUMPS REMOVAL. SIDE VIEW

Conceptual Design

GENERAL NOTES:
DIMENSIONS ARE IN METERS

Naval Facilities Engineering Service Center, Port Hueneme CA

☒ PRELIMINARY DWG ☐ CONTRACT DWG ☐ WORKING DWG ☐ AS BUILT

REV	DESCRIPTION	DATE	DRAWN	CHECK
REV1				
REV0	FOR REVIEW	8/05/10	LMCO	PG

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SCALE: NTS

DWG. NR. RS-4

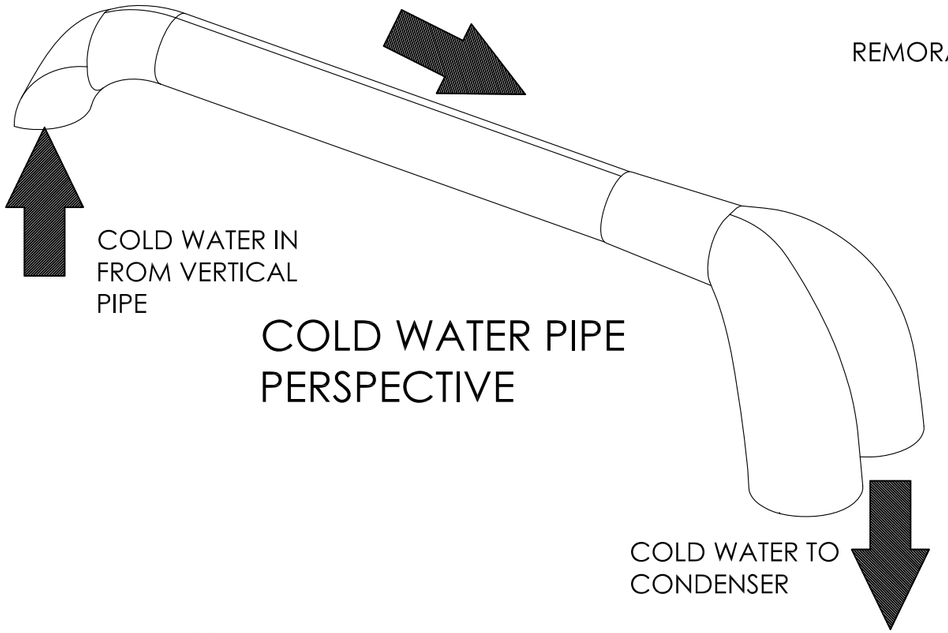
PROJECT : NAVFAC OTEC PROJECT

SUBJECT : CW and WW Pumps Removal

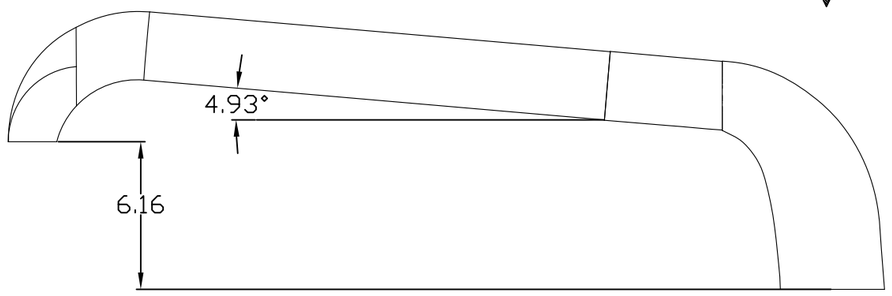
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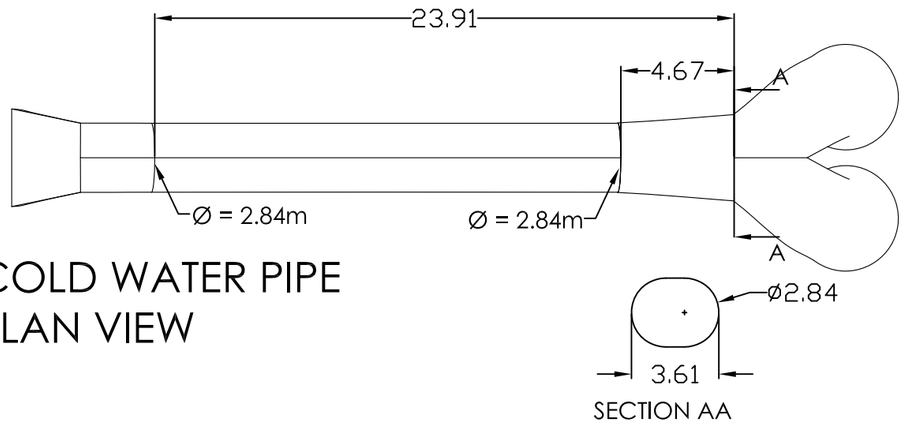
DATE: 3 JAN 2010



COLD WATER PIPE PERSPECTIVE



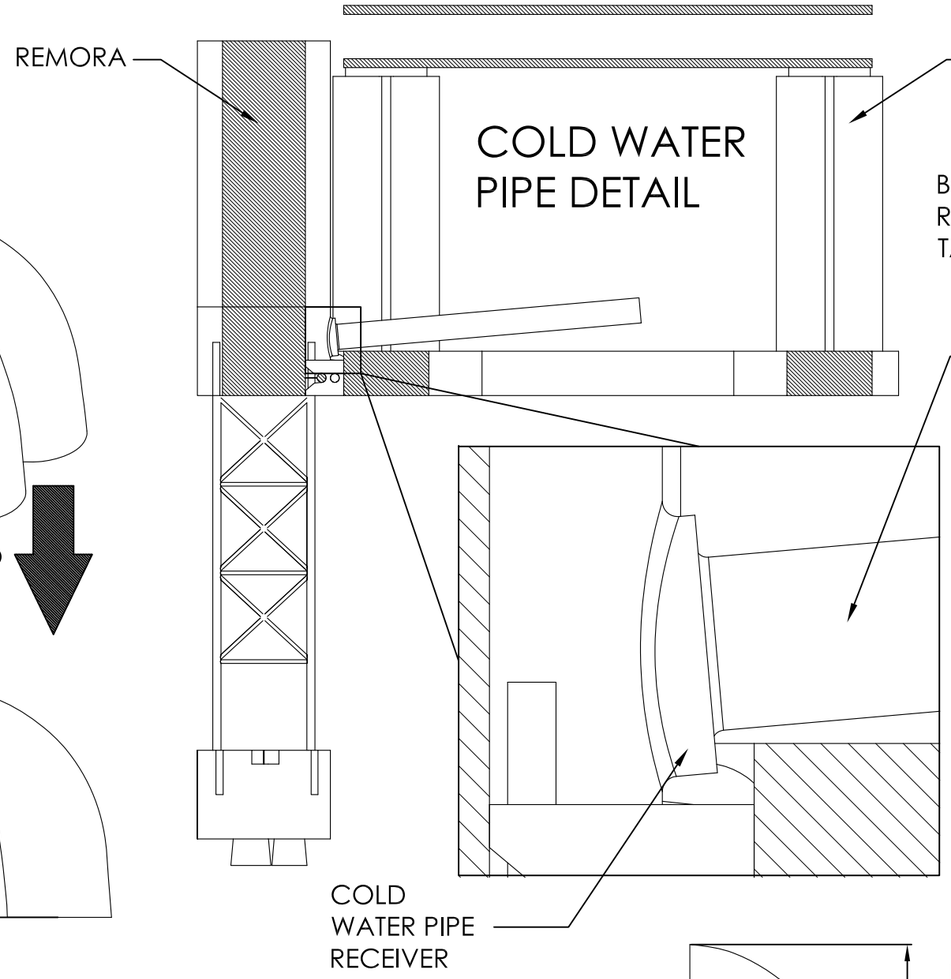
COLD WATER PIPE PROFILE VIEW

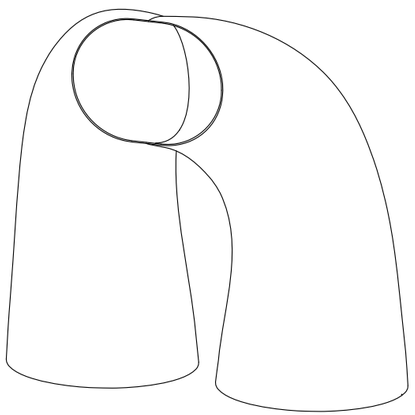


COLD WATER PIPE PLAN VIEW

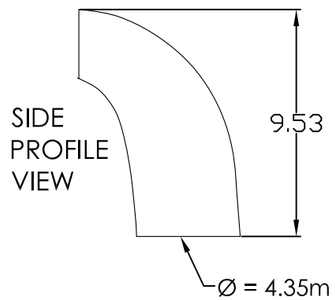
SECTION AA

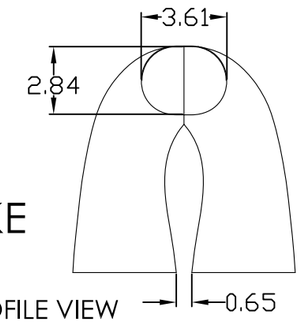
DIMENSIONS IN METERS



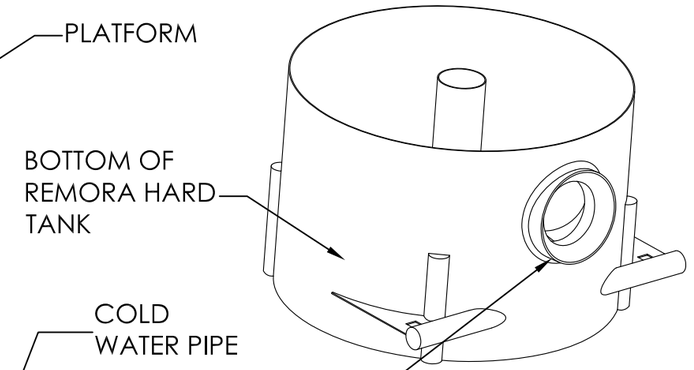


COLD WATER INTAKE PERSPECTIVE

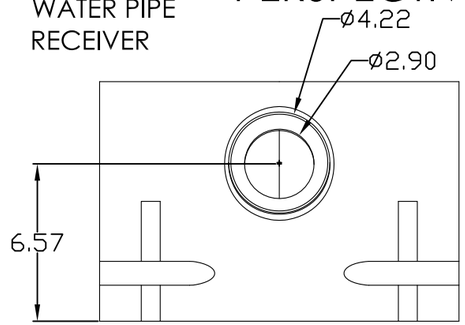




END PROFILE VIEW



PERSPECTIVE



PROFILE VIEW

COLD WATER PIPE RECEIVER

Conceptual Design

Naval Facilities Engineering Service Center, Port Hueneme CA

■ PRELIMINARY DWG ☐ CONTRACT DWG ☐ WORKING DWG ☐ AS BUILT

REV1				
REV0	FOR REVIEW	08/17/10	RSH	PG
REV	DESCRIPTION	DATE	DRAWN	CHECK

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Design & Construction
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Phone: (808) 531 7001
Fax: (808) 523 7688

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9255 Wellington Road
Manassas, Va. 20110-4121

SCALE: 1:250

DWG. NR. RS–5

PROJECT : NAVFAC OTEC PROJECT

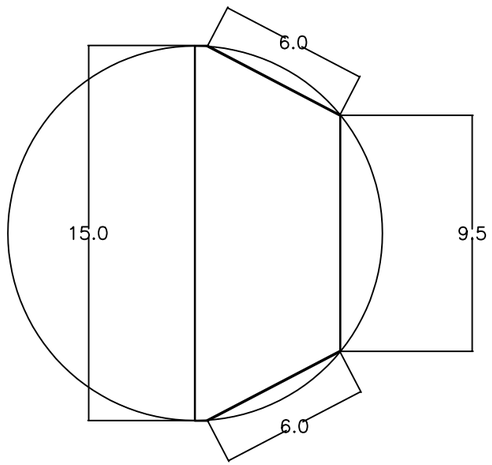
SUBJECT : COLD WATER DUCT INTERFACE

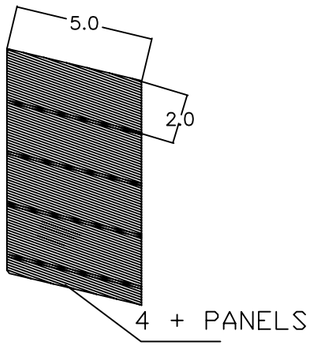
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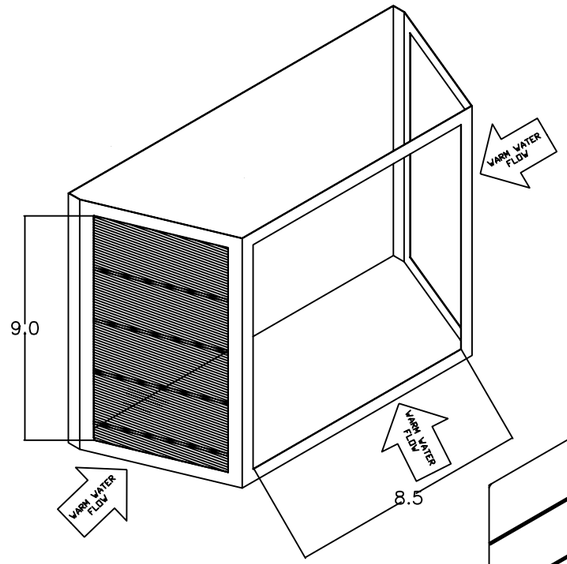
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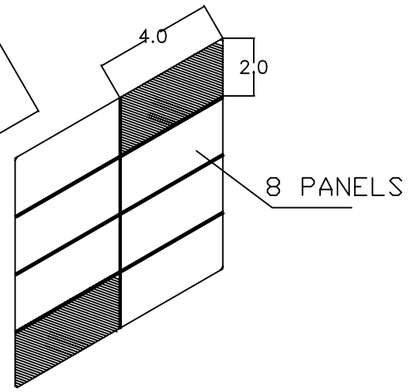
DATE: 17 AUG 2010

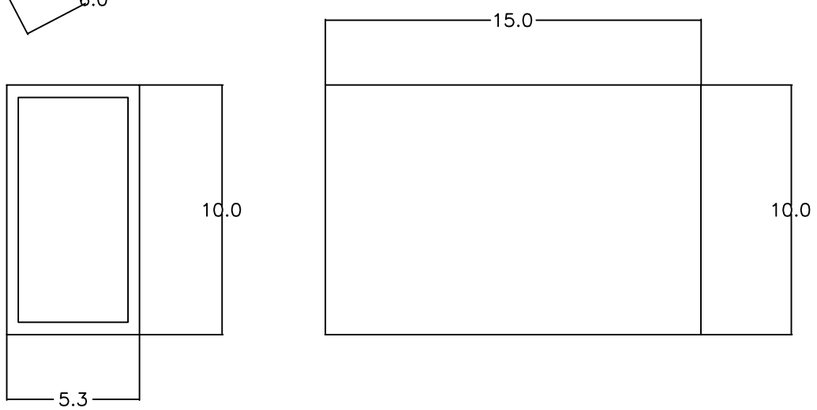
PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT











GENERAL NOTES:

TOTAL OPEN AREA ~ 165 MSQ; MESH = 8mm x 8mm with 50% clogging reserve

MATERIAL: FRP

WEIGHT OF THE SCREENS and HARDWARE 2600 KG

DIMENSIONS ARE IN METERS

Conceptual Design

PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT

Naval Facilities Engineering Service Center, Port Hueneme CA

■ PRELIMINARY DWG ☐ CONTRACT DWG ☐ WORKING DWG ☐ AS BUILT

REV	DESCRIPTION	DATE	DRAWN	CHECK
REV1				
REV0	FOR REVIEW	8/05/10	BB	

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SCALE: NTS

DWG. NR. RS-6

PROJECT: NAVFAC OTEC PROJECT

SUBJECT: REMORA WARM WATER INTAKE SCREEN

BLOCK NAME:

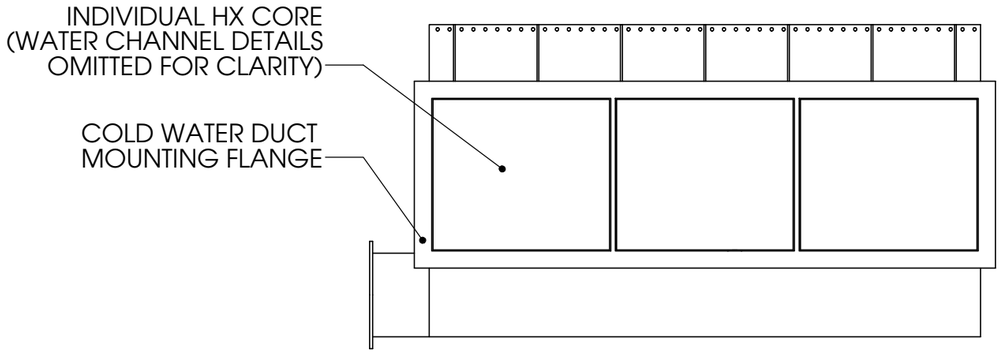
DATE: 3 JAN 2010

FILE: FILENAME

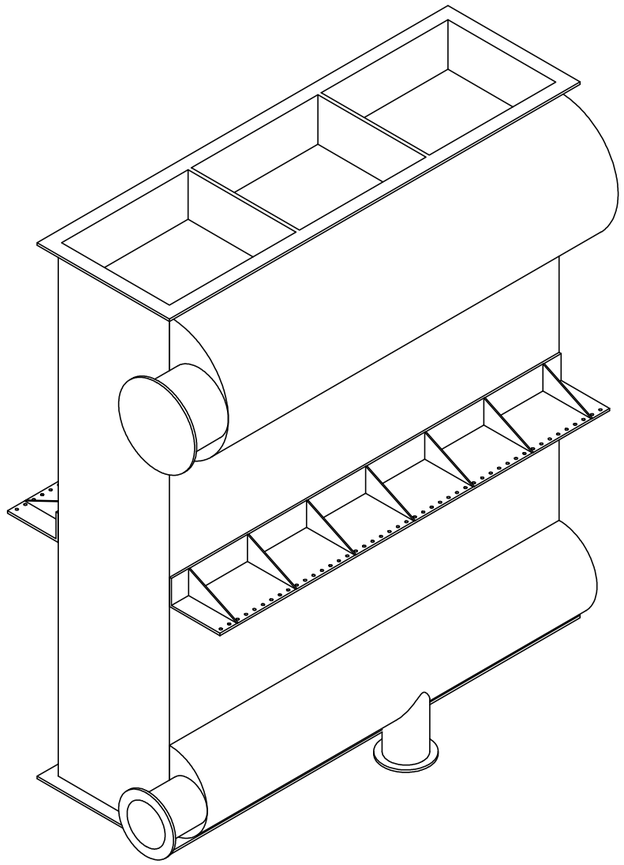
PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT

NOTES

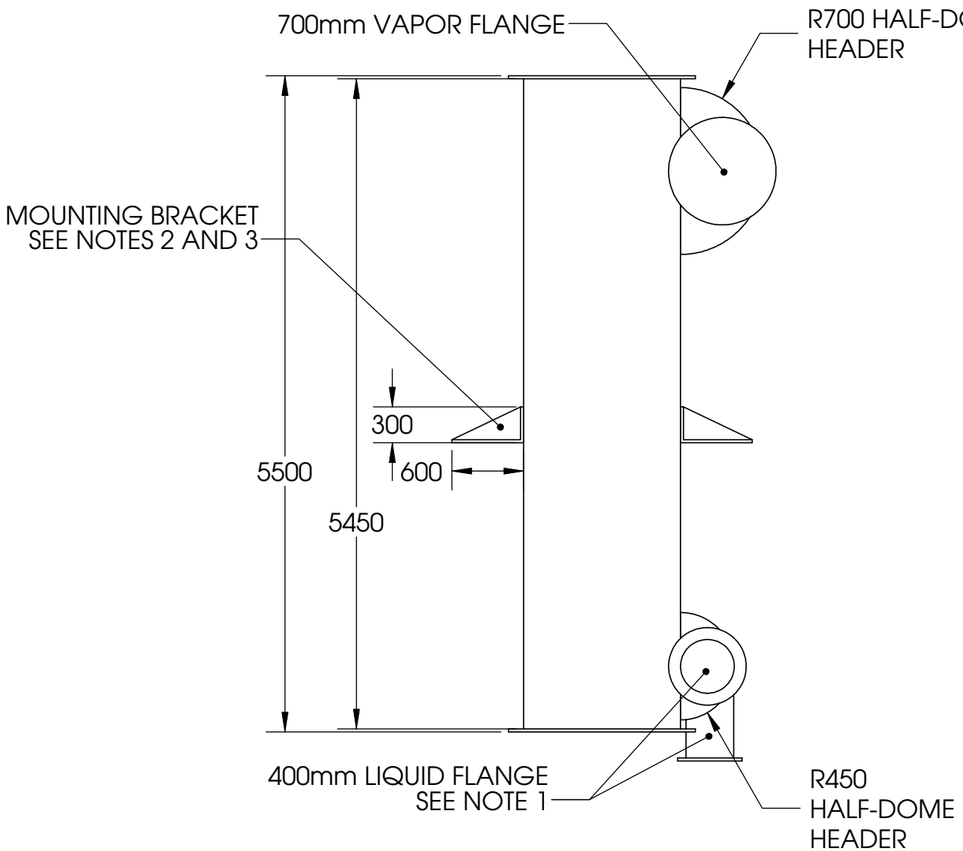
1. ONLY 1 FLANGE REQUIRED. SELECT VERTICAL OR HORIZONTAL FLANGE AS REQ'D.
2. MOUNTING BRACKET OPPOSITE HEADERS OMITTED FOR "BATTERY OF 6" CONFIGURATION
3. HX TO BE ELECTRICALLY ISOLATED FROM REMORA STRUCTURE AT MOUNTING BRACKET WITH NONCONDUCTIVE BEARING PLATE AND 2 SHOULDER WASHERS AT EACH BOLT.



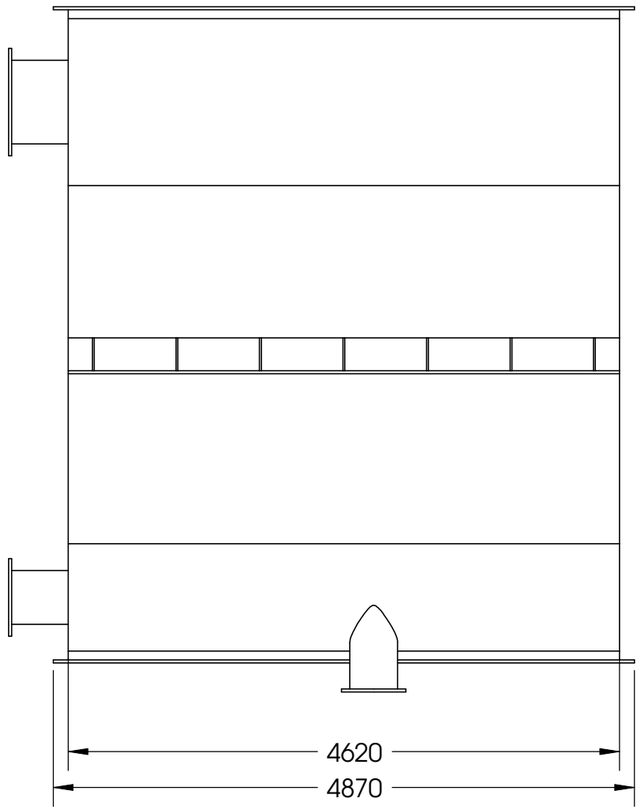
TOP VIEW



ISOMETRIC VIEW



SIDE VIEW



FRONT VIEW

Conceptual Design

Naval Facilities Engineering Service Center, Port Hueneme CA

■ PRELIMINARY DWG ☐ CONTRACT DWG ☐ WORKING DWG ☐ AS BUILT

REV	DESCRIPTION	DATE	DRAWN	CHECK
REV1				
REV0	FOR REVIEW	10/05/10	SR	SR

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SCALE: 1:50

DWG. NR. RP-10

PROJECT : NAVFAC OTEC PROJECT

SUBJECT : BATTERY OF 3 HX'S

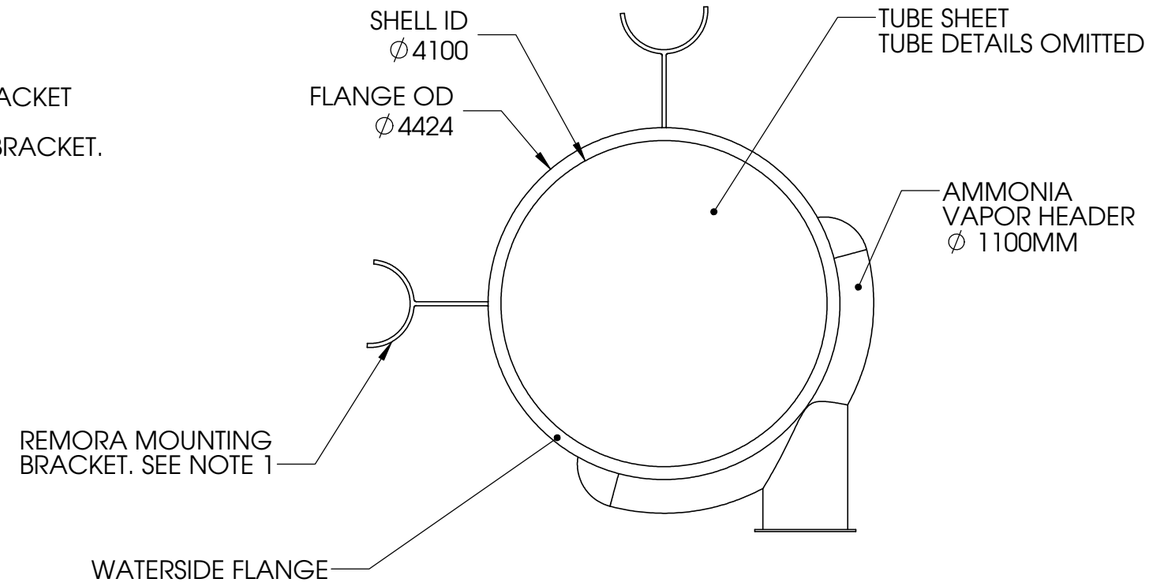
FILE: FILENAME

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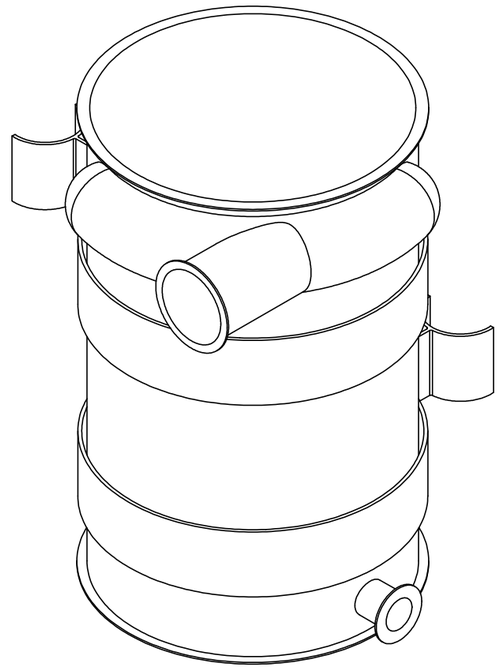
DATE: 3 JAN 2010

NOTES

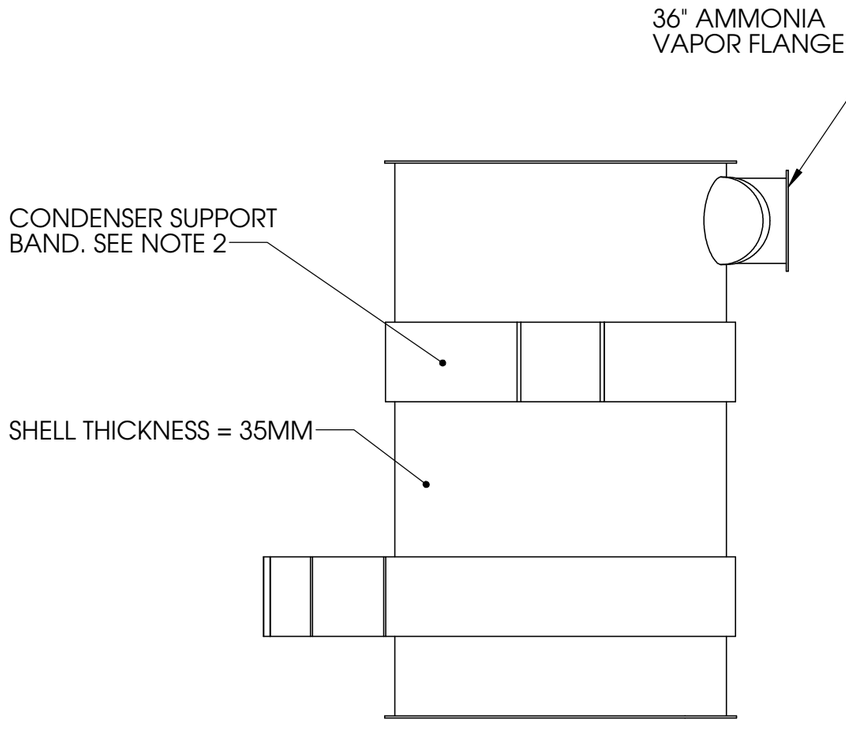
1. BRACKET TO BE WELDED TO REMORA TRUSS. BRACKET DIMENTIONS TBD.
2. BAND TO BE WELDED TO REMORA MOUNTING BRACKET. DIMENSIONS OF CONNECTING MEMBER TBD.



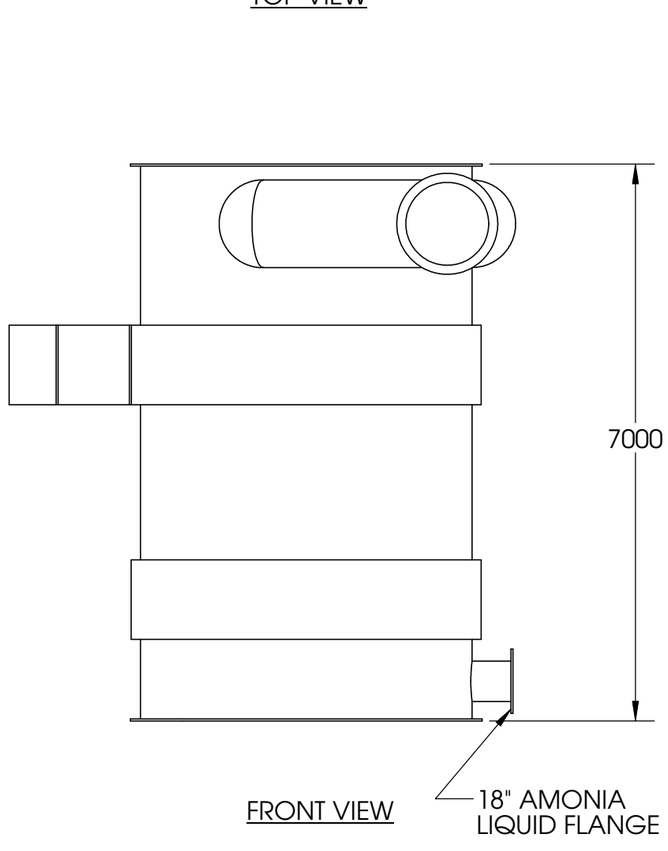
TOP VIEW



ISOMETRIC VIEW



SIDE VIEW



FRONT VIEW

Conceptual Design

Naval Facilities Engineering Service Center, Port Hueneme CA

■ PRELIMINARY DWG ☐ CONTRACT DWG ☐ WORKING DWG ☐ AS BUILT

REV	DESCRIPTION	DATE	DRAWN	CHECK
REV1				
REV0	FOR REVIEW	10/05/10	SR	SR

MAKAI

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Lockheed Martin
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SCALE: 1:60

DWG. NR. RP-11

PROJECT : NAVFAC OTEC PROJECT

SUBJECT : S&T CONDENSER

FILE: FILENAME

BLOCK NAME:

DATE: 3 JAN 2010

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-14
Weight Report – Deployed
OTEC-2010-001

17 September 2010

Prepared for:

Naval Facilities Engineering Command
Naval Facilities Engineering Service Center (NFESC)
1100 23rd Avenue
Port Hueneme, CA 93043-4370
Attn: Mr. Brian Cable, Contracting Officer Representative

Prepared by:

Lockheed Martin MS2
9500 Godwin Drive
Manassas, VA 20110

Distribution Statement A: Approved for public release; distribution is unlimited

APPENDIX 3.3.2.1.1-2

Remora Iteration 2.1 Detailed Weight Report (Deployed Orientation)

LCG origin is uppermost corner, platform side (+ right)		Weight				LCG	VCG	TCG			
VCG origin is centerline of side view (+ up from platform)		(kg)	Margin	Total (kg)		(mm)	(mm)	(mm)	REMARKS		
TCG is centerline of back view (+ port up)											
	SUMMARY OF WEIGHT GROUPS									OTEC Weight Fraction	
									Vertical orientation, LCG represents VCG	Lightship	Full Load
Group 1	Hull Structure	3425407	15	3939218		55700	7363	0	**in this configuration**	0.49	0.49
			15	0							
Group 2	Propulsion Machinery	0	15	0		0	0	0		0.00	0.00
			15	0							
Group 3	Electrical Generation	0	15	0		0	0	0		0.00	0.00
			15	0							
Group 4	Communications & Controls	0	15	0		0	0	0		0.00	0.00
			15	0							
Group 5	Auxiliary Systems	3567518	15	4102645		53111	8304	0		0.51	0.51
			15	0							
Group 6	Outfit & Furnishings	8513	15	9790		36500	0	0		0.00	0.00
	Lightship (w/o margin)	**7001438**		**8051654**		**54357**	**7833**	**0**		1.00	1.00
Group F	Variable Load	0	0	0		0	0	0			0.00
Group F	Mission Ready Fuel Weight	0	0	0		0	0	0			
Group M	Design Margin										0.00
Group M	Future Growth Margin	0	0	0							0.00
	Full Load			**8051654**		**54357**	**7833**	**0**			

VCG origin is centerline of side view (+ up from platform) TCG is centerline of back view (+ port up)							Qty	Unit Wt (kg)	WEIGHT (kg)	LCG (mm)	VCG (mm)	TCG (mm)
GROUP 1	**HULL**											
110	**Shell and Supporting Structure**								1088714			
111	Shell Plating											
		Upper Hull										
			Fr 0-10				1	45212	45212	5000	7500	0
			Fr 10-40				1	203372	203372	25000	7500	0
			Center Tube Fr 0-10				1	7505	7505	5000	7500	0
			Center Tube Fr 10-40				1	33692	33692	25000	7500	0
			Top				1	16497	16497	0	7500	0
		Middle Section										
			Penstock									
				Shell Plate Fr 40-50			1	1212	1212	45000	12000	0
				Trans Bkhd Fr 40-50			1	24005	24005	45000	7500	0
			Truss - Vertical Tubes									
				Compt 6			4	9213	36852	45000	7500	0
				Compt 7			4	9213	36852	55000	7500	0
				Compt 8			4	9213	36852	65000	7500	0
				Compt 9			4	9213	36852	75000	7500	0
			Truss - Horizontal Tubes									
				Compt 6			4	881	3524	50000	7500	0
				Compt 7			4	881	3524	60000	7500	0
				Compt 8			4	881	3524	70000	7500	0
			Truss - Braces									
				Compt 6			8	2296	18368	45000	7500	0
				Compt 7			8	2296	18368	55000	7500	0
				Compt 8			8	2296	18368	65000	7500	0
				Compt 9			8	2296	18368	75000	7500	0
		Lower Hull										
			Fr 70.5-80				0	28611	0	75250	12875	0
			Fr 70.5-80 Transverse				0	23717	0	75250	11250	0
			Fr 80-85				1	45176	45176	82500	7500	0
			Fr 85-90				1	45176	45176	87500	7500	0
113	Inner Bottom											
114	Shell Appendages											
115	Stanchions											
116	Longitudinal Stiffeners											
		Upper Hull Plate Stiffeners										
			Fr 0-10				56	130	7280	5000	7500	0
			Fr 10-30				56	619	34664	20000	7500	0
			Fr 30-40				56	470	26320	35000	7500	0
		Mid-Section										
			Fr 40-50				32	557	17824	45000	12000	0
			Fr 40-50 Trans				20	557	11140	45000	7500	0
		Lower Hull Plate Stiffeners										
			Fr 70.5-80				0	874	0	75250	12875	0
			Fr 70.5-80 Trans				0	874	0	75250	11250	0
			Fr 80-85				56	276	15456	82500	7500	0
			Fr 85-90				56	271	15176	87500	7500	0
		UH Longitudinal Diagonal Frames										
			Compt 1				4	76	304	2500	7500	0
			Compt 2				4	76	304	7500	7500	0
			Compt 3				4	464	1856	16250	7500	0
			Compt 4				4	464	1856	26250	7500	0
			Compt 5				4	464	1856	35000	7500	0
		Bulkhead Stiffeners										
			Upper Hull									
				Top			18	180	3240	0	7500	0
				Bkhd 1			18	180	3240	5000	7500	0
				Bkhd 2			18	180	3240	10000	7500	0

VCG origin is centerline of side view (+ up from platform) TCG is centerline of back view (+ port up)							Qty	Unit Wt (kg)	WEIGHT (kg)	LCG (mm)	VCG (mm)	TCG (mm)
				Bkhd 3			18	255	4590	22500	7500	0
				Bkhd 4			18	433	7794	30000	7500	0
				Bkhd 5			18	502	9036	40000	7500	0
			UH Longitudinal Bkhd Stiffs									
				Fr 0-10			16	130	2080	5000	7500	0
				Fr 10-40			16	1411	22576	25000	7500	0
			UH Transverse Bkhd Stiffs									
				Fr 0-10			16	130	2080	5000	7500	0
				Fr 10-40			16	1411	22576	25000	7500	0
			Mid-Section									
				Bkhd 6			18	164	2952	50000	12000	0
			Lower Hull									
				Bkhd 7			0	173	0	70500	12875	0
				Bkhd 8			18	380	6840	80000	7500	0
				Bkhd 9			18	398	7164	85000	7500	0
				Bkhd 10			18	382	6876	90000	7500	0
			LH Longitudinal Bkhd Stiffs									
				Fr 80-85			18	276	4968	82500	7500	0
				Fr 85-90			18	271	4878	87500	7500	0
			LH Transverse Bkhd Stiffs									
				Fr 80-85			18	276	4968	84000	7500	0
				Fr 85-90			18	271	4878	88000	7500	0
		Brackets					0.1	258012	25801	35000	7500	0
117	Transverse Framing											
		Upper Hull										
			Fr 2.5				1	6007	6007	2500	7500	0
			Fr 7.5				1	6007	6007	7500	7500	0
			Fr 12.5				1	6007	6007	12500	7500	0
			Fr 15				1	6007	6007	15000	7500	0
			Fr 17.5				1	6007	6007	17500	7500	0
			Fr 20				1	6007	6007	20000	7500	0
			Fr 25				1	8843	8843	25000	7500	0
			Fr 27.5				1	8843	8843	27500	7500	0
			Fr 32.5				1	10725	10725	32500	7500	0
			Fr 35				1	10725	10725	35000	7500	0
			Fr 37.5				1	10725	10725	37500	7500	0
		Mid-Section										
			Fr 42.5				1	8777	8777	42500	9970	0
			Fr 45				1	8777	8777	45000	9970	0
			Fr 47.5				1	8777	8777	47500	9970	0
		Lower Hull										
			Fr 73				0	11992	0	73000	12875	0
			Fr 75.5				0	11992	0	75500	12875	0
			Fr 82.5				1	19684	19684	82500	7500	0
			Fr 87.5				1	19684	19684	87500	7500	0
120	**Hull Structural Bulkheads (ex SS)**								498559			
121	Longitudinal Structural Bulkheads											
		Upper Hull										
			Fr 0-10				2	6001	12002	5000	7500	0
			Fr 10-40				2	27005	54010	25000	7500	0
		Lower Hull										
			Fr 80-85				1	14403	14403	82500	7500	0
			Fr 85-90				1	14403	14403	87500	7500	0
122	Transverse Structural Bulkheads											
		Upper Hull										
			Bkhd 1				1	16497	16497	5000	7500	0
			Bkhd 2				1	16497	16497	10000	7500	0
			Bkhd 3				1	24745	24745	22500	7500	0
			Bkhd 4				1	24745	24745	30000	7500	0
			Bkhd 5				1	24745	24745	40000	7500	0

VCG origin is centerline of side view (+ up from platform) TCG is centerline of back view (+ port up)		Qty	Unit Wt (kg)	WEIGHT (kg)	LCG (mm)	VCG (mm)	TCG (mm)
	Transverse						
	Fr 0-10	2	6001	12002	5000	7500	0
	Fr 10-40	2	27005	54010	25000	7500	0
	UH Longitudinal Diagonal Frames						
	Compt 1	4	1500	6000	2500	7500	0
	Compt 2	4	1500	6000	7500	7500	0
	Compt 3	4	6751	27004	16250	7500	0
	Compt 4	4	6751	27004	26250	7500	0
	Compt 5	4	6751	27004	35000	7500	0
	Mid-Section						
	Bkhd 6	1	6874	6874	50000	12000	0
	Lower Hull						
	Bkhd 7	0	6634	0	70500	1625	0
	Bkhd 8	1	33936	33936	80000	7500	0
	Bkhd 9	1	33936	33936	85000	7500	0
	Bkhd 10	1	33936	33936	90000	7500	0
	Transverse						
	Fr 80-85	1	14403	14403	82500	7500	0
	Fr 85-90	1	14403	14403	87500	7500	0
123	Trunks & Enclosures						
130	**Structural Decks (ex SS)**			0			
131	Lower Hull Decks						
132	Spar Wet Decks						
136	Upper Hull Deck						
140	**Hull Platforms & Flats**			0			
141	1st Platform						
149	Flats						
150	**Deckhouse Structure**			0			
151	Deckhouse Structure to First Level						
160	**Special Structures**			72000			
161	Structural Castings, Forgings, Weldments						
	Platform Mounts	4	18000	72000	20000	0	0
163	Sea Chests						
166	Sponsons						
	Skirt Assembly	0	16800	0	98700	7500	0
167	Hull Structural Closures						
	Lower Deck WT Hatches						
	Upper Deck WT Hatches						
168	Deckhouse Structural Closures						
169	Special Purpose Closures						
170	**Masts, Kingposts, Service Platforms**			0			
171	Masts, Towers, Tetrapods						
172	Kingposts & Support Frames						
180	**Foundations**			109262			
181	Hull Structure Foundations						
	Platform Mount Foundations	4		0			
	Skirt Foundation	0.1	0	0	90000	7500	0
182	Propulsion Plant Foundations						
183	Electrical Plant Foundations						
184	Command & Surveillance Foundations						
185	Auxiliary Systems Foundations						
	Condenser Foundation	0.1	200000	20000	43500	4470	0
	Evaporator Foundation	0.1	336300	33630	60000	7660	0
	NH3 Buffer Tank Foundation	0.1	15157	1516	54000	3830	0

VCG origin is centerline of side view (+ up from platform) TCG is centerline of back view (+ port up)		Qty	Unit Wt (kg)	WEIGHT (kg)		LCG (mm)	VCG (mm)	TCG (mm)
	NH3 Module Foundation	0.1	17230		1723	73100	10530	0
	NH3 Demister Foundation	0.1	12156		1216	53850	8000	0
	WW Pump Foundation	0.1	50000		5000	80000	7780	0
	CW Pump Foundation	0.1	40000		4000	80000	3200	0
	WW Piping Foundation	0.1	106405		10641	55000	7780	0
	CW Piping Foundation	0.1	114376		11438	63100	3200	0
	NH3 Piping Foundation	0.1	201000		20100	52000	10200	0
186	Outfit & Furnishing Foundations							
190	**Special Purpose Systems**			1656872				
191	Ballast (Fixed or Fluid)							
	Upper Hull Water	0.3	1752326		525698	38500	7500	0
	Lower Hull Water	0.6	1796863		1078118	85000	7500	0
	LH Extra Tank	0			0	75250	1625	0
199	Hull Repair Parts & Special Tools							
	Welding	0.030	1768536		53056	42660	6350	
	GROUP 1 TOTAL			3425407	3425407	55700	7363	0

LCG origin is uppermost corner, platform side (+ right) VCG origin is centerline of side view (+ up from platform) TCG is centerline of back view (+ port up)							Qty	Unit Wt (kg)	WEIGHT (kg)	LCG (mm)	VCG (mm)	TCG (mm)
GROUP 5	**AUXILIARY SYSTEMS**											
500	**Auxiliary Systems, General**											
501	General Arrangement - Auxiliary Systems Drawings											
502	Auxiliary Machinery											
503	Pumps											
504	Instruments & Instrument Boards											
505	General Piping Requirements											
506	Overflows, Air Escapes & Sounding Tubes											
507	Machinery & Piping Designation and Marking											
508	Thermal Insulation for Piping & Machinery											
509	Thermal Insulation for Vent & A/C Ducts											
510	**Climate Control**								0			
511	Compartment Heating System											
512	Ventilation System											
		Mist Eliminators										
		Fans										
		Piping, Vents, Plenums										
		Dampers										
		Goose Necks										
513	Machinery Space Ventilation System											
514	Air-Conditioning System											
516	Refrigeration Systems											
520	**Sea Water Systems**								854062			
521	Firemain & Flushing System											
524	Auxiliary Seawater System											
		Cold Water System										
			Condenser									
				Heat Exchangers			2	100000	200000	43500	4600	
				Misc								
			Seawater Pump				1	40000	40000	77000	3330	
			Hardware									
				Misc								
			Trunking									
				Intake			1	32668	32668	36500	3400	0
				Converger			1	17090	17090	46500	3400	0

VCG origin is centerline of side view (+ up from platform) TCG is centerline of back view (+ port up)		Qty	Unit Wt (kg)	WEIGHT (kg)	LCG (mm)	VCG (mm)	TCG (mm)
	Mid Section	1	36283	36283	57700	3400	0
	Discharge	1	28335	28335	87000	3400	0
	Screen						
	Inner						
	Outer						
	Warm Water System						
	Evaporator						
	Heat Exchangers	2	168150	336300	60000	7780	
	Misc						
	Seawater Pump	1	50000	50000	77000	7780	
	Hardware						
	Misc						
	Trunking						
	Intake	1	49582	49582	60000	11000	0
	Converger	1	27800	27800	64600	11000	0
	Discharge	1	29023	29023	87000	11000	0
	Screen						
	Inner	1					
	Outer	1					
526	Scuppers & Deck Drains						
528	Plumbing Drainage						
529	Drainage & Ballasting System						
	Ballast System						
	Level Sensors						
	Pumps						
	Piping, Hose						
	Valves						
	Bilge System						
	Level Sensors	18	2	40	22000	7500	
	Pumps	18	154	2772	22000	7500	
	Piping, Hose	9	423	3807	22000	7500	
	Valves			0	22000	7500	
	Misc	0.1	3620	362	22000	7500	
530	**Fresh Water Systems**			0			
540	**Fuels & Lubricants, Handling & Storage**			0			
541	Ship Fuel & Fuel Compensating System						
550	**Air, Gas & Misc. Fluid Systems**			245543			
551	Compressed Air Systems						
555	Fire Extinguishing Systems						

VCG origin is centerline of side view (+ up from platform) TCG is centerline of back view (+ port up)		Qty	Unit Wt (kg)	WEIGHT (kg)	LCG (mm)	VCG (mm)	TCG (mm)
	Fire Suppression						
	CO2	0	354	0			
	CO2 Tank	0	5019	0			
	Piping	0	292	0			
	Misc	0	5665	0			
	Portable Firefighting Equipment						
556	Hydraulic Fluid System						
558	NH3 System						
	Buffer Tanks	2	7579	15157	52280	3830	
	Demisters	2	6078	12156	53850	8000	
	Pump Module						
	Pump	2					
	Motor	2					
	Enclosure	2	8615	17230	52000	10530	
	Piping	1	134000	134000	52000	10200	0
	Brackets	1	67000	67000	52000	10200	0
	Flanges	1		0	52000	10200	
	Valves	1		0	52000	10200	
	Hardware						
	Misc						
560	**Ship Control Systems**			0			
561	Steering & Diving Control Systems						
562	Rudder						
565	Trim & Heel Systems (Surface Ships)						
567	Strut & Foil Systems						
568	Maneuvering Systems						
570	**Underway Replenishment Systems**			0			
572	Ship Stores & Equipment Handling Systems						
580	**Mechanical Handling Systems**			0			
581	Anchor Handling & Stowage Systems						
582	Mooring & Towing Systems						
	Cleats						
	Bitts						
	Eyes						
	Ropes, Lines						
583	Boats, Boat Handling & Stowage Systems						
585	Elevating & Retracting Gear						
589	Misc Mechanical Handling Systems						
590	**Special Purpose Systems**			2467913			

VCG origin is centerline of side view (+ up from platform)									WEIGHT		LCG	VCG	TCG
TCG is centerline of back view (+ port up)							Qty	Unit Wt (kg)	(kg)		(mm)	(mm)	(mm)
592	Swimmer & Diver Support and Protection Systems												
593	Environmental Pollution Control Systems												
595	Towing, Launching & Handling for Underwater Systems												
596	Handling System for Diver and Submersible Vehicles												
598	Auxiliary Systems Operating Fluids												
		Cold Seawater					1	728273		728273	50000	3400	0
		Warm Seawater					1	1723640		1723640	52000	11000	0
		NH3					1	16000		16000	52000	8145	0
599	Auxiliary Systems Repair Parts & Special Tools												
	TOTAL GROUP 5								3567518	3567518	53111	8304	0

VCG origin is centerline of side view (+ up from platform) TCG is centerline of back view (+ port up)		Qty	Unit Wt (kg)	WEIGHT (kg)		LCG (mm)	VCG (mm)	TCG (mm)
GROUP 6	**OUTFIT & FURNISHINGS**							
600	**Outfit & Furnishings, General**							
601	General Arrangement - Outfit & Furnishing Drawings							
602	Hull Designating & Marking							
603	Draft Marks							
604	Locks, Keys & Tags							
605	Rodent & Vermin Proofing							
610	**Ship Fittings**			0				
611	Hull Fittings							
	Rub Rail							
	Lifting Eyes							
	Fittings							
612	Rails, Stanchions & Lifelines							
	Handrails							
613	Rigging & Canvas							
	Ropes, Lines							
620	**Hull Compartmentation**			0				
621	Non-Structural Bulkheads							
622	Floor Plates & Gratings							
623	Ladders							
624	Non-Structural Closures							
625	Airports, Fixed Portlights & Windows							
630	**Preservatives & Coverings**			8513				
631	Painting							
	Copper Antifoul							
	Topside Paint	1	7035		7035	36500	0	0
632	Zinc & Metallic Coatings							
633	Cathodic Protection	112	13		1478	36500	0	0
634	Deck Covering							
635	Hull Insulation							
660	**Working Spaces**			0				
661	Offices							
662	Machinery Control Center Furnishings							
663	Electronics Control Center Furnishings							
670	**Stowage Spaces**			0				
671	Lockers & Special Stowage							
672	Storerooms & Issue Rooms							
673	Cargo Stowage							
690	**Special Purpose Systems**			0				
691	Transmission Loss Treatment							
698	Outfit & Furnishing Operating Fluids							
699	Outfit & Furnishing Repair Parts & Special Tools				0	0	0	0
	GROUP 6 TOTAL			8513	8513	36500.00	0.00	0.00

Piping (2-Stage)															Globe
Schedule 40 Pipe							Pipe	NH_3	NH_3		Flange	Flange		900# Valve	Valve
	Qty		OD (in)	Lgth (mm)	OD (mm)	ID (mm)	Wt (kg)	Density (kg/mm_3)	Wt (kg)	Flanges	Unit Wt (kg)	Wt (kg)	Valves	Unit Wt (kg)	Wt (kg)
1.00	1.00	demister-evaporator	40.00	4500.00	1000.00	965.00	1908.11	0.00	22.68	1.00	36.42	36.42	0.00		0.00
	4.00		20.00	3000.00	508.00	478.00	2188.46	0.00	14.84	4.00	10.24	40.98			0.00
	4.00		12.00	3000.00	324.00	303.00	974.15	0.00	4.79	4.00	3.06	12.26			0.00
2.00	1.00	evaporator-pump wye	20.00	10000.00	508.00	478.00	1823.72	0.00	9.94	1.00	10.24	10.24	0.00		0.00
3.00	1.00	demister-holding tank	12.00	2000.00	324.00	303.00	162.36	0.00	0.99	4.00	3.06	12.26	2.00	621.00	1242.00
4.00	1.00	holding tank-recirc pump	12.00	20000.00	324.00	303.00	1623.59	0.00	9.94	6.00	3.06	18.38	2.00	621.00	1242.00
5.00	1.00	recirc pump-pump wye	12.00	5000.00	324.00	303.00	405.90	0.00	2.48	6.00	3.06	18.38	3.00	621.00	1863.00
6.00	0.50	demister-turbine	32.00	26000.00	800.00	778.00	2782.48	0.00	42.58	1.00	13.39	13.39	0.00		0.00
7.00	1.00	pump wye-feed pump	16.00	10000.00	406.00	381.00	1213.04	0.00	5.54	6.00	5.57	33.44	3.00	1147.00	3441.00
8.00	0.50	turbine-condenser	40.00	43000.00	1000.00	965.00	9116.51	0.00	76.42	1.00	36.42	36.42	0.00		0.00
	4.00		20.00	3000.00	508.00	478.00	2188.46	0.00	10.47	4.00	10.24	40.98			0.00
	4.00		8.00	3000.00	219.00	203.00	499.54	0.00	1.89	4.00	1.14	4.56			0.00
	1.00	vent	6.00	12000.00	168.00	154.00	333.52		0.00	1.00	0.63	0.63			0.00
9.00	1.00	condenser-buffer	16.00	10000.00	406.00	381.00	1213.04	0.00	5.54	1.00	5.57	5.57			0.00
10.00	1.00	buffer-feed pump	16.00	10000.00	406.00	381.00	1213.04	0.00	5.54	6.00	5.57		2.00	1147.00	2294.00
							27645.92		213.64			283.91			10082.00

ρ_{water} (kg/m^3)	1025.00						
					Est Water		
Component	Qty	Surf Area (m^2)	Volume (m^3)	Wt (kg)	Wt (kg)		
Warm Water							
Penstock	1.00	713.50	883.00	77071.00	905075.00		
Top	1.00	507.54	270.00	49582.00	276750.00		
Hx	3.00	483.02	33.50	525808.00	103012.50	6 x hx w/ 50% permeability	
Mid	1.00	292.08	267.40	27799.66	274085.00		
Pump	0.50	192.14	73.00	7069.00	37412.50	50% permeability	
Bottom	1.00	297.38	124.20	29023.30	127305.00		
Cold Water							
Intake	1.00	348.59	200.00	32668.00	205000.00		
Hx	0.80	377.38	101.70	35815.00	83394.00	2 x hx w/40% permeability	
Converger	1.00	180.40	85.50	17090.00	87637.50		
Middle	1.00	381.77	180.90	36182.53	185422.50		
Pump	0.50	191.13	77.10	19550.56	39513.75	50% permeability	
Bottom	1.00	298.07	124.20	28335.17	127305.00		
	OD	L	t	Body	End	Total Wt (kg)	
NH3 Buffer Tank	2500.00	3500.00	25.40	691125062.55	137150154.28	7578.59	
NH3 Separator	2000.00	3800.00	25.40	598751092.17	87776098.74	6078.28	
NH3 Pump Module	2200.00	5100.00	25.40	884979374.59	106209079.48	8614.57	

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-15
Weight Report – Towing
OTEC-2010-001

17 September 2010

Prepared for:

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Naval Facilities Engineering Service Center (NFESC)
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Distribution Statement A: Approved for public release; distribution is unlimited

APPENDIX 3.3.2.1.1-3

Remora Iteration 2.1 Detailed Weight Report (Towing Orientation)

LCG origin is uppermost corner, platform side (+ right)		Weight				LCG	VCG	TCG			
VCG origin is centerline of side view (+ up from platform)		(kg)	Margin	Total (kg)		(mm)	(mm)	(mm)	REMARKS		
TCG is centerline of back view (+ port up)											
	SUMMARY OF WEIGHT GROUPS									OTEC Weight Fraction	
									Vertical orientation, LCG represents VCG	Lightship	Full Load
Group 1	Hull Structure	1821592	15	2094830		43322	7243	0	**in this configuration**	0.39	0.39
			15	0							
Group 2	Propulsion Machinery	0	15	0		0	0	0		0.00	0.00
			15	0							
Group 3	Electrical Generation	0	15	0		0	0	0		0.00	0.00
			15	0							
Group 4	Communications & Controls	0	15	0		0	0	0		0.00	0.00
			15	0							
Group 5	Auxiliary Systems	2822072	15	3245383		53587	9742	0		0.61	0.61
			15	0							
Group 6	Outfit & Furnishings	8513	15	9790		36500	0	0		0.00	0.00
	Lightship (w/o margin)	**4652177**		**5350004**		**49536**	**8746**	**0**		1.00	1.00
Group F	Variable Load	0	0	0		0	0	0			0.00
Group F	Mission Ready Fuel Weight	0	0	0		0	0	0			
Group M	Design Margin										0.00
Group M	Future Growth Margin	0	0	0							0.00
	Full Load			**5350004**		**49536**	**8746**	**0**			
							6254.33				

VCG origin is centerline of side view (+ up from platform) TCG is centerline of back view (+ port up)							Qty	Unit Wt (kg)	WEIGHT (kg)	LCG (mm)	VCG (mm)	TCG (mm)
GROUP 1	**HULL**											
110	**Shell and Supporting Structure**								1088714			
111	Shell Plating											
		Upper Hull										
			Fr 0-10				1	45212	45212	5000	7500	0
			Fr 10-40				1	203372	203372	25000	7500	0
			Center Tube Fr 0-10				1	7505	7505	5000	7500	0
			Center Tube Fr 10-40				1	33692	33692	25000	7500	0
			Top				1	16497	16497	0	7500	0
		Middle Section										
			Penstock									
				Shell Plate Fr 40-50			1	1212	1212	45000	12000	0
				Trans Bkhd Fr 40-50			1	24005	24005	45000	7500	0
			Truss - Vertical Tubes									
				Compt 6			4	9213	36852	45000	7500	0
				Compt 7			4	9213	36852	55000	7500	0
				Compt 8			4	9213	36852	65000	7500	0
				Compt 9			4	9213	36852	75000	7500	0
			Truss - Horizontal Tubes									
				Compt 6			4	881	3524	50000	7500	0
				Compt 7			4	881	3524	60000	7500	0
				Compt 8			4	881	3524	70000	7500	0
			Truss - Braces									
				Compt 6			8	2296	18368	45000	7500	0
				Compt 7			8	2296	18368	55000	7500	0
				Compt 8			8	2296	18368	65000	7500	0
				Compt 9			8	2296	18368	75000	7500	0
		Lower Hull										
			Fr 70.5-80				0	28611	0	75250	12875	0
			Fr 70.5-80 Transverse				0	23717	0	75250	11250	0
			Fr 80-85				1	45176	45176	82500	7500	0
			Fr 85-90				1	45176	45176	87500	7500	0
113	Inner Bottom											
114	Shell Appendages											
115	Stanchions											
116	Longitudinal Stiffeners											
		Upper Hull Plate Stiffeners										
			Fr 0-10				56	130	7280	5000	7500	0
			Fr 10-30				56	619	34664	20000	7500	0
			Fr 30-40				56	470	26320	35000	7500	0
		Mid-Section										
			Fr 40-50				32	557	17824	45000	12000	0
			Fr 40-50 Trans				20	557	11140	45000	7500	0
		Lower Hull Plate Stiffeners										
			Fr 70.5-80				0	874	0	75250	12875	0
			Fr 70.5-80 Trans				0	874	0	75250	11250	0
			Fr 80-85				56	276	15456	82500	7500	0
			Fr 85-90				56	271	15176	87500	7500	0
		UH Longitudinal Diagonal Frames										
			Compt 1				4	76	304	2500	7500	0
			Compt 2				4	76	304	7500	7500	0
			Compt 3				4	464	1856	16250	7500	0
			Compt 4				4	464	1856	26250	7500	0
			Compt 5				4	464	1856	35000	7500	0
		Bulkhead Stiffeners										
			Upper Hull									
				Top			18	180	3240	0	7500	0
				Bkhd 1			18	180	3240	5000	7500	0
				Bkhd 2			18	180	3240	10000	7500	0

VCG origin is centerline of side view (+ up from platform) TCG is centerline of back view (+ port up)							Qty	Unit Wt (kg)	WEIGHT (kg)	LCG (mm)	VCG (mm)	TCG (mm)
				Bkhd 3			18	255	4590	22500	7500	0
				Bkhd 4			18	433	7794	30000	7500	0
				Bkhd 5			18	502	9036	40000	7500	0
			UH Longitudinal Bkhd Stiffs									
				Fr 0-10			16	130	2080	5000	7500	0
				Fr 10-40			16	1411	22576	25000	7500	0
			UH Transverse Bkhd Stiffs									
				Fr 0-10			16	130	2080	5000	7500	0
				Fr 10-40			16	1411	22576	25000	7500	0
			Mid-Section									
				Bkhd 6			18	164	2952	50000	12000	0
			Lower Hull									
				Bkhd 7			0	173	0	70500	12875	0
				Bkhd 8			18	380	6840	80000	7500	0
				Bkhd 9			18	398	7164	85000	7500	0
				Bkhd 10			18	382	6876	90000	7500	0
			LH Longitudinal Bkhd Stiffs									
				Fr 80-85			18	276	4968	82500	7500	0
				Fr 85-90			18	271	4878	87500	7500	0
			LH Transverse Bkhd Stiffs									
				Fr 80-85			18	276	4968	84000	7500	0
				Fr 85-90			18	271	4878	88000	7500	0
		Brackets					0.1	258012	25801	35000	7500	0
117	Transverse Framing											
		Upper Hull										
			Fr 2.5				1	6007	6007	2500	7500	0
			Fr 7.5				1	6007	6007	7500	7500	0
			Fr 12.5				1	6007	6007	12500	7500	0
			Fr 15				1	6007	6007	15000	7500	0
			Fr 17.5				1	6007	6007	17500	7500	0
			Fr 20				1	6007	6007	20000	7500	0
			Fr 25				1	8843	8843	25000	7500	0
			Fr 27.5				1	8843	8843	27500	7500	0
			Fr 32.5				1	10725	10725	32500	7500	0
			Fr 35				1	10725	10725	35000	7500	0
			Fr 37.5				1	10725	10725	37500	7500	0
		Mid-Section										
			Fr 42.5				1	8777	8777	42500	9970	0
			Fr 45				1	8777	8777	45000	9970	0
			Fr 47.5				1	8777	8777	47500	9970	0
		Lower Hull										
			Fr 73				0	11992	0	73000	12875	0
			Fr 75.5				0	11992	0	75500	12875	0
			Fr 82.5				1	19684	19684	82500	7500	0
			Fr 87.5				1	19684	19684	87500	7500	0
120	**Hull Structural Bulkheads (ex SS)**								498559			
121	Longitudinal Structural Bulkheads											
		Upper Hull										
			Fr 0-10				2	6001	12002	5000	7500	0
			Fr 10-40				2	27005	54010	25000	7500	0
		Lower Hull										
			Fr 80-85				1	14403	14403	82500	7500	0
			Fr 85-90				1	14403	14403	87500	7500	0
122	Transverse Structural Bulkheads											
		Upper Hull										
			Bkhd 1				1	16497	16497	5000	7500	0
			Bkhd 2				1	16497	16497	10000	7500	0
			Bkhd 3				1	24745	24745	22500	7500	0
			Bkhd 4				1	24745	24745	30000	7500	0
			Bkhd 5				1	24745	24745	40000	7500	0

VCG origin is centerline of side view (+ up from platform) TCG is centerline of back view (+ port up)		Qty	Unit Wt (kg)	WEIGHT (kg)	LCG (mm)	VCG (mm)	TCG (mm)
	Transverse						
	Fr 0-10	2	6001	12002	5000	7500	0
	Fr 10-40	2	27005	54010	25000	7500	0
	UH Longitudinal Diagonal Frames						
	Compt 1	4	1500	6000	2500	7500	0
	Compt 2	4	1500	6000	7500	7500	0
	Compt 3	4	6751	27004	16250	7500	0
	Compt 4	4	6751	27004	26250	7500	0
	Compt 5	4	6751	27004	35000	7500	0
	Mid-Section						
	Bkhd 6	1	6874	6874	50000	12000	0
	Lower Hull						
	Bkhd 7	0	6634	0	70500	1625	0
	Bkhd 8	1	33936	33936	80000	7500	0
	Bkhd 9	1	33936	33936	85000	7500	0
	Bkhd 10	1	33936	33936	90000	7500	0
	Transverse						
	Fr 80-85	1	14403	14403	82500	7500	0
	Fr 85-90	1	14403	14403	87500	7500	0
123	Trunks & Enclosures						
130	**Structural Decks (ex SS)**			0			
131	Lower Hull Decks						
132	Spar Wet Decks						
136	Upper Hull Deck						
140	**Hull Platforms & Flats**			0			
141	1st Platform						
149	Flats						
150	**Deckhouse Structure**			0			
151	Deckhouse Structure to First Level						
160	**Special Structures**			72000			
161	Structural Castings, Forgings, Weldments						
	Platform Mounts	4	18000	72000	20000	0	0
163	Sea Chests						
166	Sponsons						
	Skirt Assembly	0	16800	0	98700	7500	0
167	Hull Structural Closures						
	Lower Deck WT Hatches						
	Upper Deck WT Hatches						
168	Deckhouse Structural Closures						
169	Special Purpose Closures						
170	**Masts, Kingposts, Service Platforms**			0			
171	Masts, Towers, Tetrapods						
172	Kingposts & Support Frames						
180	**Foundations**			109262			
181	Hull Structure Foundations						
	Platform Mount Foundations	4		0			
	Skirt Foundation	0.1	0	0	90000	7500	0
182	Propulsion Plant Foundations						
183	Electrical Plant Foundations						
184	Command & Surveillance Foundations						
185	Auxiliary Systems Foundations						
	Condenser Foundation	0.1	200000	20000	43500	4470	0
	Evaporator Foundation	0.1	336300	33630	60000	7660	0
	NH3 Buffer Tank Foundation	0.1	15157	1516	54000	3830	0

VCG origin is centerline of side view (+ up from platform) TCG is centerline of back view (+ port up)		Qty	Unit Wt (kg)	WEIGHT (kg)		LCG (mm)	VCG (mm)	TCG (mm)
	NH3 Module Foundation	0.1	17230		1723	73100	10530	0
	NH3 Demister Foundation	0.1	12156		1216	53850	8000	0
	WW Pump Foundation	0.1	50000		5000	80000	7780	0
	CW Pump Foundation	0.1	40000		4000	80000	3200	0
	WW Piping Foundation	0.1	106405		10641	55000	7780	0
	CW Piping Foundation	0.1	114376		11438	63100	3200	0
	NH3 Piping Foundation	0.1	201000		20100	52000	10200	0
186	Outfit & Furnishing Foundations							
190	**Special Purpose Systems**			53056				
191	Ballast (Fixed or Fluid)							
	Upper Hull Water	0	402517		0	2500	0	4000
	Lower Hull Water	0	1796863		0	85000	7500	0
	LH Extra Tank	0			0	75250	1625	0
199	Hull Repair Parts & Special Tools							
	Welding	0.030	1768536		53056	42660	6350	
	GROUP 1 TOTAL			1821592	1821592	43322	7243	0

VCG origin is centerline of side view (+ up from platform) TCG is centerline of back view (+ port up)							Qty	Unit Wt (kg)	WEIGHT (kg)	LCG (mm)	VCG (mm)	TCG (mm)
GROUP 5	**AUXILIARY SYSTEMS**											
500	**Auxiliary Systems, General**											
501	General Arrangement - Auxiliary Systems Drawings											
502	Auxiliary Machinery											
503	Pumps											
504	Instruments & Instrument Boards											
505	General Piping Requirements											
506	Overflows, Air Escapes & Sounding Tubes											
507	Machinery & Piping Designation and Marking											
508	Thermal Insulation for Piping & Machinery											
509	Thermal Insulation for Vent & A/C Ducts											
510	**Climate Control**								0			
511	Compartment Heating System											
512	Ventilation System											
		Mist Eliminators										
		Fans										
		Piping, Vents, Plenums										
		Dampers										
		Goose Necks										
513	Machinery Space Ventilation System											
514	Air-Conditioning System											
516	Refrigeration Systems											
520	**Sea Water Systems**								764062			
521	Firemain & Flushing System											
524	Auxiliary Seawater System											
		Cold Water System										
			Condenser									
				Heat Exchangers			2	100000	200000	43500	4600	
				Misc								
			Seawater Pump				0	40000	0	77000	3330	
			Hardware									
				Misc								
			Trunking									
				Intake			1	32668	32668	36500	3400	0
				Converger			1	17090	17090	46500	3400	0
				Mid Section			1	36283	36283	57700	3400	0
				Discharge			1	28335	28335	87000	3400	0
			Screen									
				Inner								
				Outer								
		Warm Water System										
			Evaporator									
				Heat Exchangers			2	168150	336300	60000	7780	
				Misc								
			Seawater Pump				0	50000	0	77000	7780	
			Hardware									
				Misc								
			Trunking									
				Intake			1	49582	49582	60000	11000	0
				Converger			1	27800	27800	64600	11000	0
				Discharge			1	29023	29023	87000	11000	0
			Screen									
				Inner			1					
				Outer			1					

| VCG origin is centerline of side view (+ up from platform)
TCG is centerline of back view (+ port up) | | |

VCG origin is centerline of side view (+ up from platform) TCG is centerline of back view (+ port up)		Qty	Unit Wt (kg)	WEIGHT (kg)		LCG (mm)	VCG (mm)	TCG (mm)
	Eyes							
	Ropes, Lines							
583	Boats, Boat Handling & Stowage Systems							
585	Elevating & Retracting Gear							
589	Misc Mechanical Handling Systems							
590	**Special Purpose Systems**			1812467				
592	Swimmer & Diver Support and Protection Systems							
593	Environmental Pollution Control Systems							
595	Towing, Launching & Handling for Underwater Systems							
596	Handling System for Diver and Submersible Vehicles							
598	Auxiliary Systems Operating Fluids							
	Cold Seawater	0.1	728273		72827	70000	6000	0
	Warm Seawater	1	1723640		1723640	52000	11250	0
	NH3	1	16000		16000	52000	8145	0
599	Auxiliary Systems Repair Parts & Special Tools							
	TOTAL GROUP 5			2822072	2822072	53587	9742	0

VCG origin is centerline of side view (+ up from platform)							WEIGHT		LCG	VCG	TCG
TCG is centerline of back view (+ port up)					Qty	Unit Wt (kg)	(kg)		(mm)	(mm)	(mm)
GROUP 6	**OUTFIT & FURNISHINGS**										
600	**Outfit & Furnishings, General**										
601	General Arrangement - Outfit & Furnishing Drawings										
602	Hull Designating & Marking										
603	Draft Marks										
604	Locks, Keys & Tags										
605	Rodent & Vermin Proofing										
610	**Ship Fittings**						0				
611	Hull Fittings										
	Rub Rail										
	Lifting Eyes										
	Fittings										
612	Rails, Stanchions & Lifelines										
	Handrails										
613	Rigging & Canvas										
	Ropes, Lines										
620	**Hull Compartmentation**						0				
621	Non-Structural Bulkheads										
622	Floor Plates & Gratings										
623	Ladders										
624	Non-Structural Closures										
625	Airports, Fixed Portlights & Windows										
630	**Preservatives & Coverings**						8513				
631	Painting										
	Copper Antifoul										
	Topside Paint					1	7035		7035	36500	0	0
632	Zinc & Metallic Coatings										
633	Cathodic Protection					112	13		1478	36500	0	0
634	Deck Covering										
635	Hull Insulation										
660	**Working Spaces**						0				
661	Offices										
662	Machinery Control Center Furnishings										
663	Electronics Control Center Furnishings										
670	**Stowage Spaces**						0				
671	Lockers & Special Stowage										
672	Storerooms & Issue Rooms										
673	Cargo Stowage										
690	**Special Purpose Systems**						0				
691	Transmission Loss Treatment										
698	Outfit & Furnishing Operating Fluids										
699	Outfit & Furnishing Repair Parts & Special Tools								0	0	0	0
	GROUP 6 TOTAL						8513		8513	36500.00	0.00	0.00

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-16
Weight and Buoyancy – Deployed
OTEC-2010-001

17 September 2010

Prepared for:

Naval Facilities Engineering Command
Naval Facilities Engineering Service Center (NFESC)
1100 23rd Avenue
Port Hueneme, CA 93043-4370
Attn: Mr. Brian Cable, Contracting Officer Representative

Prepared by:

Lockheed Martin MS2
9500 Godwin Drive
Manassas, VA 20110

Distribution Statement A: Approved for public release; distribution is unlimited

APPENDIX 3.3.2.1.1-4

Remora Iteration 2.1 Calculation of Longitudinal Weight and Buoyancy Distribution

Deployed Configuration

				Deck w s	Longs										
	Shell	Center	Truss	Rings	Trans	Section Weight (kg)									
Frame	& Stiffs	Tube	V&D	Truss H	Diags	Hull Struct Tot	Misc Struct	Total Struct	Auxiliary	CW & WW Piping	NH3 Piping	Water	Ballast	NH3	Total
0		808		23762		24570		24570							24570
1	6304	808			4886	11998	11001	22999			3302			263	26564
2	6304	808			4886	11998	11001	22999			3302			263	26564
3	6304	808		7115	4886	19113	11001	30114			3302			263	33679
4	6304	808			4886	11998	11001	22999			3302			263	26564
5	6304	808		23762	4886	35760	340	36100			3302			263	39665
6	6304	808			4886	11998	340	12338			3302			263	15903
7	6304	808			4886	11998	340	12338			3302			263	15903
8	6304	808		7115	4886	19113	340	19453			3302			263	23018
9	6304	808			4886	11998	340	12338			3302			263	15903
10	6304	808		23762	4886	35760	340	36100			3302			263	39665
11	10678	1330			9666	21675	340	22015			3302			263	25580
12	10678	1330		7115	9666	28790	340	29131			3302			263	32696
13	10678	1330			9666	21675	340	22015			3302			263	25580
14	10678	1330			9666	21675	340	22015			3302			263	25580
15	10678	1330		7115	9666	28790	340	29131			3302			263	32696
16	10678	1330			9666	21675	340	22015			3302			263	25580
17	10678	1330			9666	21675	340	22015			3302			263	25580
18	10678	1330		7115	9666	28790	340	29131			3302			263	32696
19	10678	1330			9666	21675	340	22015			3302			263	25580
20	10678	1330		7115	9666	28790	340	29131			3302			263	32696
21	10678	1330			9666	21675	340	22015			3302			263	25580
22	10678	1330			9666	21675	340	22015			3302			263	25580
23	10678	1330		35291	9666	56966	340	57306			3302			263	60871
24	10678	1330			9666	21675	340	22015			3302			263	25580
25	10678	1330		10475	9666	32150	340	32490			3302			263	36055
26	10678	1330			9666	21675	340	22015			3302			263	25580
27	10678	1330			9666	21675	340	22015			3302			263	25580
28	10678	1330		10475	9666	32150	340	32490			3302			263	36055
29	10678	1330			9666	21675	340	22015			3302			263	25580
30	10678	1330		39466	9666	61141	340	61481			3302			263	65046
31	10678	1330			9666	21675	340	22015			3302			263	25580
32	10678	1330			9666	21675	340	22015			3302			263	25580
33	10678	1330		12704	9666	34379	340	34719		2631	3302	23389		263	64304
34	10678	1330			9666	21675	340	22015		2631	3302	23389	201517	263	253117
35	10678	1330		12704	9666	34379	586	34965		2631	3302	23389	201517	263	266067
36	10678	1330			9666	21675	586	22262		2631	3302	23389	201517	263	253364
37	10678	1330			9666	21675	11247	32922		2631	3302	23389	201517	263	264024
38	10678	1330		12704	9666	34379	11247	45626		2631	3302	23389	201517	263	276728
39	10678	1330			9666	21675	11247	32922		2631	3302	23389	201517	263	264024
40	10678	1330		41084	9666	62759	14124	76883	27929		3302	23389	201517	263	333283
41	7063		6541			13604	3463	17067	27929		3302	127540		263	176101
42	7063		6541			13604	3463	17067	27929		3302	127540		263	176101
43	7063		6541	10396		24000	3463	27464	27929		3302	127540		263	186497
44	7063		6541			13604	3463	17067	27929		3302	127540		263	176101
45	7063		6541	10396		24000	3463	27464	27929		3302	127540		263	186497
46	7063		6541			13604	3750	17354	27929	2631	3302	127540		263	179018
47	7063		6541			13604	873	14477		2631	3302	127540		263	148213
48	7063		6541	10396		24000	873	24873		2631	3302	127540		263	158609
49	7063		6541			13604	873	14477		2631	3302	127540		263	148213
50	7063		6541	16163		29767	873	30640	3486	2631	3302	127540		263	167861
51			6541			6541	1471	8012	3486	6230	3302	50957		263	72250
52			6541			6541	1471	8012	3486	6230	3302	50957		263	72250
53			6541			6541	1471	8012	6981	6230	3302	50957		263	75745
54			6541			6541	873	7414	6981	6230	3302	50957		263	75146
55			6541			6541	2914	9455	3495	6230	3302	50957		263	73701
56			6541			6541	873	7414	3495	6230	3302	50957		263	71660
57			6541			6541	873	7414		6230	3302	50957		263	68165
58			6541			6541	6795	13336	57500	2631	3302	50957		263	127989
59			6541			6541	6795	13336	57500	2631	3302	50957		263	127989
60			6541	4174		10715	6795	17510	57500	2631	3302	50957		263	132163

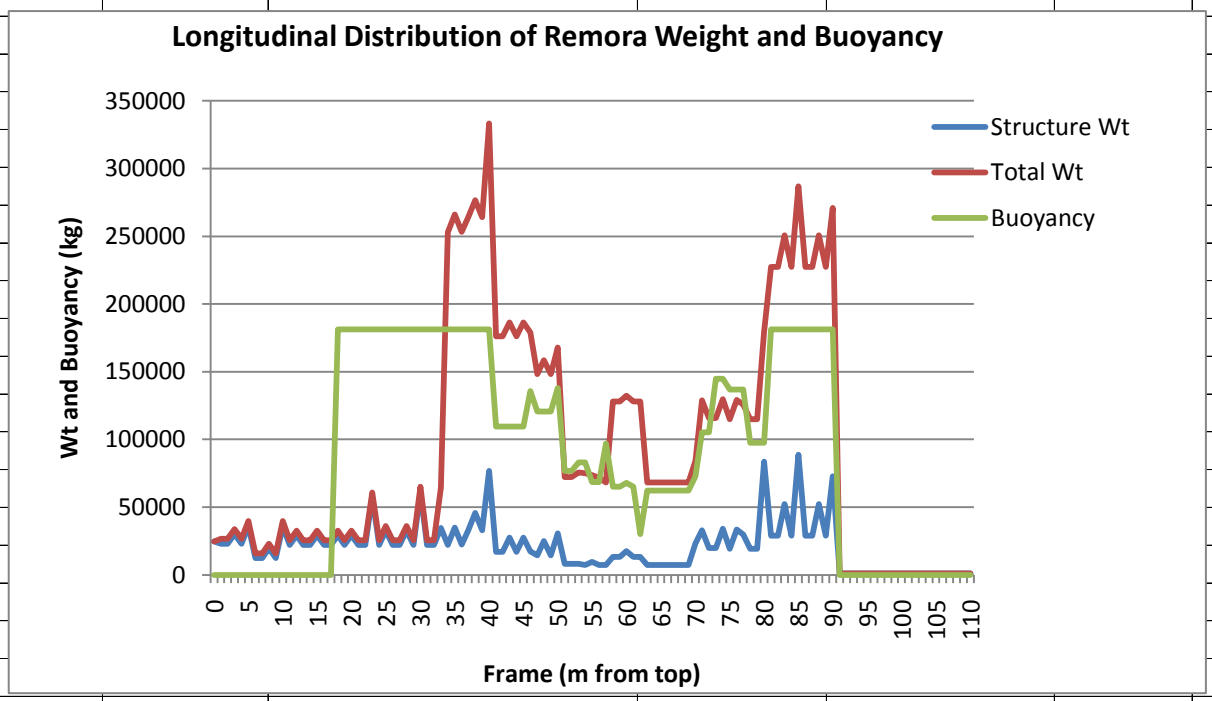
				Deck w s	Longs										
	Shell	Center	Truss	Rings	Trans	Section Weight (kg)									
Frame	& Stiffs	Tube	V&D	Truss H	Diags	Hull Struct Tot	Misc Struct	Total Struct	Auxiliary	CW & WW Piping	NH3 Piping	Water	Ballast	NH3	Total
61			6541			6541	6795	13336	57500	2631	3302	50957		263	127989
62			6541			6541	6795	13336	57500	2631	3302	50957		263	127989
63			6541			6541	873	7414		6230	3302	50957		263	68165
64			6541			6541	873	7414		6230	3302	50957		263	68165
65			6541			6541	873	7414		6230	3302	50957		263	68165
66			6541			6541	873	7414		6230	3302	50957		263	68165
67			6541			6541	873	7414		6230	3302	50957		263	68165
68			6541			6541	873	7414		6230	3302	50957		263	68165
69			6541			6541	873	7414		6230	3302	50957		263	68165
70	12073		6541	4174		22788	533	23321		6230	3302	50957		263	84073
71	12073		6541	13879		32494	533	33026		6230		50957	38634		128846
72	12073		6541			18614	1213	19827		6230		50957	38634		115648
73	12073		6541			18614	1213	19827		6230		50957	38634		115648
74	12073		6541	14205		32819	1213	34032		6230		50957	38634		129852
75	12073		6541			18614	533	19147		6230		50957	38634		114967
76	12073		6541	14205		32819	533	33352		6230		50957	38634		129172
77	12073		6541			18614	11193	29808		6230		50957	38634		125628
78	12073		6541			18614	533	19147		6230		50957	38634		114967
79	12073		6541			18614	533	19147		6230		50957	38634		114967
80	17400		6541	59159		83100	533	83632		6230		50957	38634		179452
81	17400				11120	28520	533	29052		6230		50957	141062		227301
82	17400				11120	28520	533	29052		6230		50957	141062		227301
83	17400			23316	11120	51835	533	52368		6230		50957	141062		250617
84	17400				11120	28520	533	29052		6230		50957	141062		227301
85	17400			59581	11120	88100	533	88633		6230		50957	141062		286882
86	17400				11120	28520	533	29052		6230		50957	141062		227301
87	17400				11120	28520	533	29052		6230		50957	141062		227301
88	17400			23316	11120	51835	533	52368		6230		50957	141062		250617
89	17400				11120	28520	533	29052		6230		50957	141062		227301
90				59206	11120	70325	2523	72848		6230		50957	141062		271097
91							995	995							995
92							995	995							995
93							995	995							995
94							995	995							995
95							995	995							995
96							995	995							995
97							995	995							995
98							995	995							995
99							995	995							995
100							995	995							995
101							995	995							995
102							995	995							995
103							995	995							995
104							995	995							995
105							995	995							995
106							995	995							995
107							995	995							995
108							995	995							995
109							995	995							995
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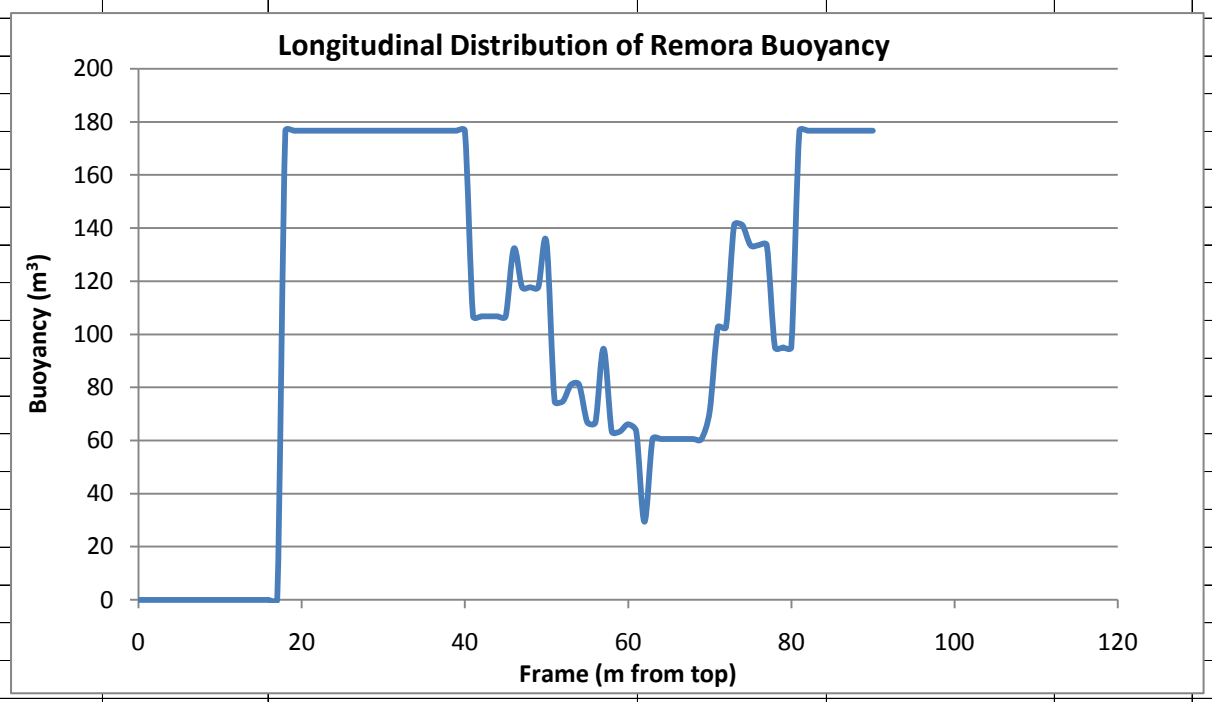
	Displaced Volume (m^3)				
Frame	Structure	Systems	CW & WW Piping	Total (m^3)	Total (kg)
0	0			0	0
1	0			0	0
2	0			0	0
3	0			0	0
4	0			0	0
5	0			0	0
6	0			0	0
7	0			0	0
8	0			0	0
9	0			0	0
10	0			0	0
11	0			0	0
12	0			0	0
13	0			0	0
14	0			0	0
15	0			0	0
16	0			0	0
17	0			0	0
18	177			177	181132
19	177			177	181132
20	177			177	181132
21	177			177	181132
22	177			177	181132
23	177			177	181132
24	177			177	181132
25	177			177	181132
26	177			177	181132
27	177			177	181132
28	177			177	181132
29	177			177	181132
30	177			177	181132
31	177			177	181132
32	177			177	181132
33	177			177	181132
34	177			177	181132
35	177			177	181132
36	177			177	181132

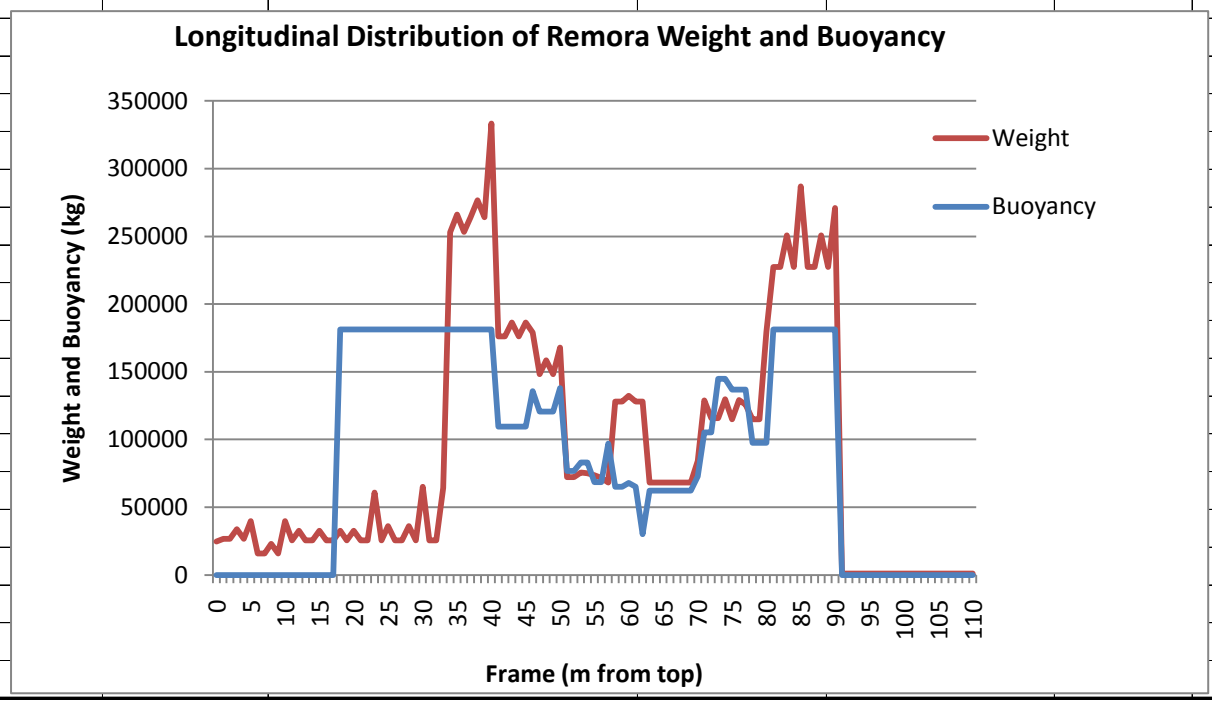
	Displaced Volume (m^3)				
Frame	Structure	Systems	CW & WW Piping	Total (m^3)	Total (kg)
37	177			177	181132
38	177			177	181132
39	177			177	181132
40	177			177	181132
41	92	15		107	109476
42	92	15		107	109476
43	92	15		107	109476
44	92	15		107	109476
45	92	15		107	109476
46	92	15	26	132	135632
47	92		26	118	120747
48	92		26	118	120747
49	92		26	118	120747
50	95	14	26	135	138020
51	4	14	57	75	76623
52	4	14	57	75	76623
53	4	20	57	81	83063
54	4	20	57	81	83063
55	4	6	57	67	68573
56	4	6	57	67	68573
57	4	34	57	95	96982
58	4	34	26	63	65031
59	4	34	26	63	65031
60	7	34	26	66	67813
61	4	34	26	63	65031
62	4		26	29	30181
63	4		57	61	62132
64	4		57	61	62132
65	4		57	61	62132
66	4		57	61	62132
67	4		57	61	62132
68	4		57	61	62132
69	4		57	61	62132
70	7	8	57	71	72707
71	38	8	57	103	105288
72	38	8	57	103	105288
73	38	46	57	141	144734
74	38	46	57	141	144734

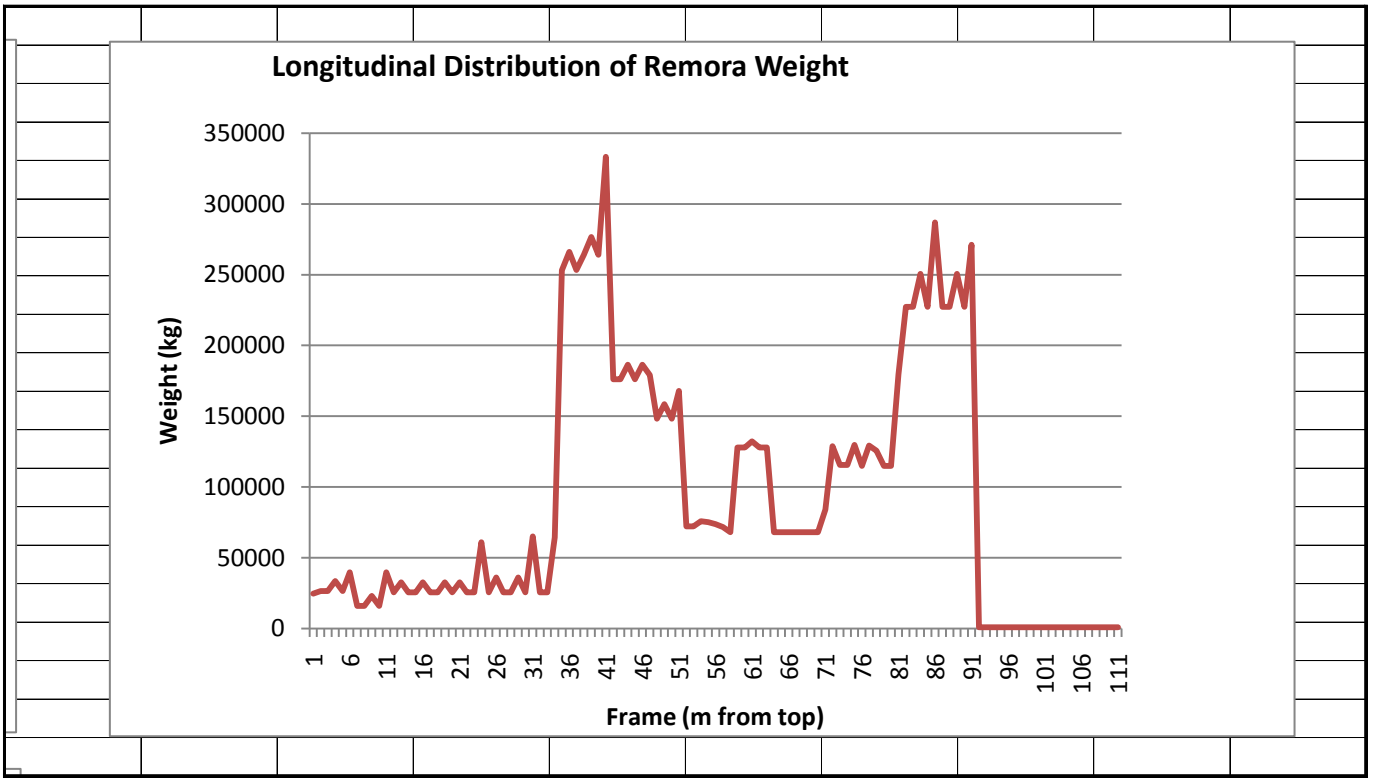
	Displaced Volume (m^3)				
Frame	Structure	Systems	CW & WW Piping	Total (m^3)	Total (kg)
75	38	38	57	134	136942
76	38	38	57	134	136942
77	38	38	57	134	136942
78	38		57	95	97495
79	38		57	95	97495
80	38		57	95	97495
81	177			177	181132
82	177			177	181132
83	177			177	181132
84	177			177	181132
85	177			177	181132
86	177			177	181132
87	177			177	181132
88	177			177	181132
89	177			177	181132
90	177			177	181132
91					0
92					0
93					0
94					0
95					0
96					0
97					0
98					0
99					0
100					0
101					0
102					0
103					0
104					0
105					0
106					0
107					0
108					0
109					0
110					0
	7225	583	1672	9481	9718220

Notes:				
Structure wt includes 3% for welding				
Difference in steel density with SW			1.038961	
Structural weight increased by 1.093 to match wt rpt				
ρ_{sw} (kg/m^3)			1025	
System Weights				
Foundation Wt (%)	0.1			
	System (kg)	Foundation (kg)		
Platform Mounts	85284			
Skirt Assembly	19899.6	1990		
Condenser	195500	20137		
Evaporator	287500	29613		
NH3 Buffer Tank	17431	1795		
NH3 Module	19815	2041		
NH3 Demister	13979	1440		
WW Pump	57500	5923		
CW Pump	46000	4738		
WW Piping	122366	12604		
CW Piping	131532	13548		
NH3 Piping	231150	23808		
LH Ballast	1239836			
LH Extra Tank Ballast	386336			
UH Ballast	1410622			
CW	1309775			
WW	1102725			
WW Tank	1041511			
NH3	18400			
UH Dia (m)	15.0			
Truss Verts Dia (m)	1.0	Lgth Short (m)	Lgth Long (m)	
Truss Horiz Dia (m)	0.3	14.76	14.76	
Truss Brace Dia (m)	0.5			
LH Dia (m)	15.0			
WW Trunk Dia (m)	6.3			
CW Trunk Dia (m)	5.7			
LH Extra Tank CS A (m2)	34.5			
Condenser OD (m)	4.3			
Evaporator Area (m2)	34.0			
NH3 Buffer Tank Dia (m)	3.0			
NH3 Demister Dia (m)	2.0			
NH3 Pump Module Dia (m)	2.2			
CW Pump Dia (m)	3.5			
WW Pump Dia (m)	3.5			


Longitudinal Distribution of Remora Weight and Buoyancy
Wt and Buoyancy (kg)
350000
300000
250000
200000
150000
100000
50000
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110
Frame (m from top)
Structure Wt
Total Wt
Buoyancy


Longitudinal Distribution of Remora Buoyancy
Buoyancy (m³)
200
180
160
140
120
100
80
60
40
20
0
0 20 40 60 80 100 120
Frame (m from top)


Longitudinal Distribution of Remora Weight and Buoyancy
Weight and Buoyancy (kg)
350000
300000
250000
200000
150000
100000
50000
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110
Frame (m from top)
Weight
Buoyancy


Longitudinal Distribution of Remora Weight
Weight (kg)
350000
300000
250000
200000
150000
100000
50000
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
Frame (m from top)

2nd (Later) Calculation

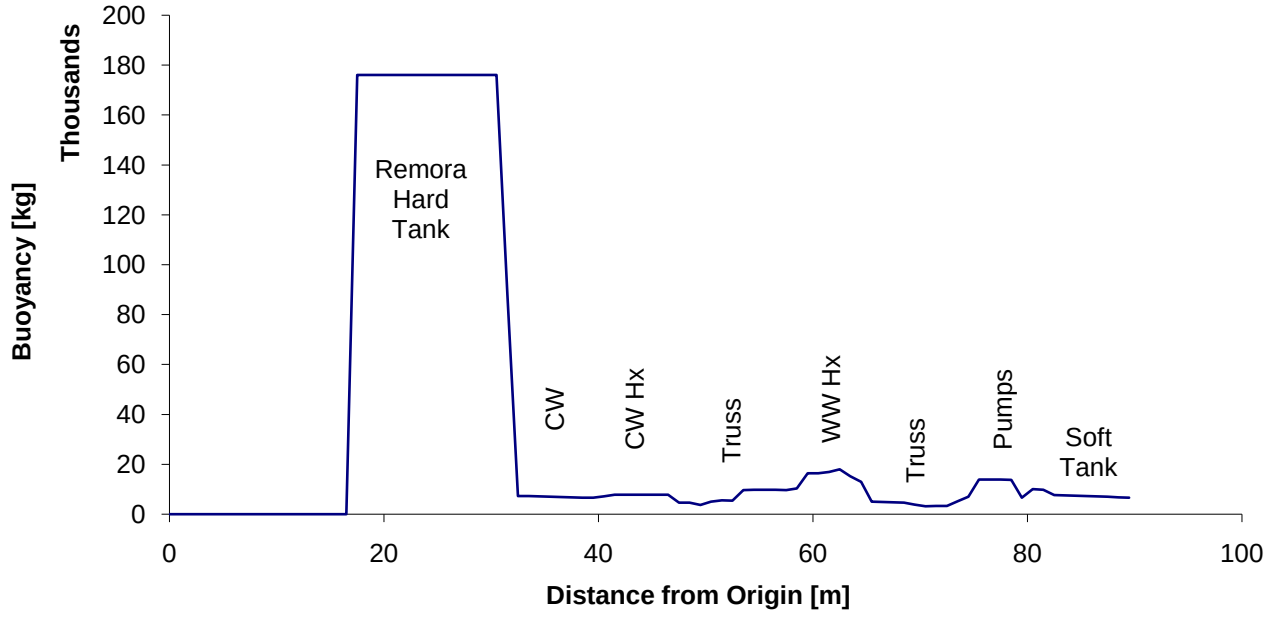
Remora Iteration 2.1 Calculation of Longitudinal Weight and Buoyancy Distribution

Deployed Configuration

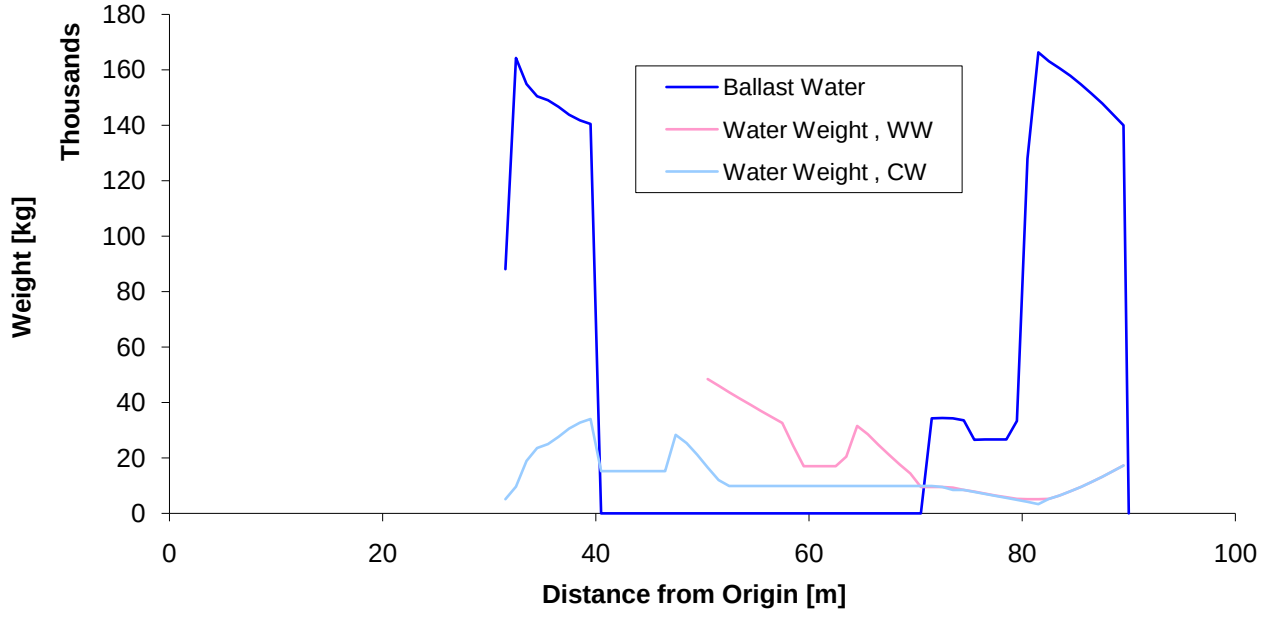
	[m3]	Volume/meter [m^3/m]						Ballast	Water Weight	Water Weight
Station	Buoyancy		Remora					Water	, CW	, WW
[m]	Total	Total	Only	CW	WW	PVs		[m3]	[m3]	[m3]
0	0	0	0	0	0	0				
0.5	0	0	0	0	0	0				
1.5	0	0	0	0	0	0				
2.5	0	0	0	0	0	0				
3.5	0	0	0	0	0	0				
4.5	0	0	0	0	0	0				
5.5	0	0	0	0	0	0				
6.5	0	0	0	0	0	0				
7.5	0	0	0	0	0	0				
8.5	0	0	0	0	0	0				
9.5	0	0	0	0	0	0				
10.5	0	0	0	0	0	0				
11.5	0	0	0	0	0	0				
12.5	0	0	0	0	0	0				
13.5	0	0	0	0	0	0				
14.5	0	0	0	0	0	0				
15.5	0	0	0	0	0	0				
16.5	0	0	0	0	0	0				
17.5	176071.8	171.7774	171.7774	0	0	0				
18.5	176071.8	171.7774	171.7774	0	0	0				
19.5	176071.8	171.7774	171.7774	0	0	0				
20.5	176071.8	171.7774	171.7774	0	0	0				
21.5	176071.8	171.7774	171.7774	0	0	0				
22.5	176071.8	171.7774	171.7774	0	0	0				
23.5	176071.8	171.7774	171.7774	0	0	0				
24.5	176071.8	171.7774	171.7774	0	0	0				
25.5	176071.8	171.7774	171.7774	0	0	0				
26.5	176071.8	171.7774	171.7774	0	0	0				
27.5	176071.8	171.7774	171.7774	0	0	0				
28.5	176071.8	171.7774	171.7774	0	0	0				
29.5	176071.8	171.7774	171.7774	0	0	0				
30.5	176071.8	171.7774	171.7774	0	0	0				
31.5	88035.2	85.888	85.888	0	0	0		88036.63804	5060.613398	
32.5	7298.246	7.12024	7.911378	0	0	0		164241.4602	9592.74535	
33.5	7298.246	7.12024	7.911378	0	0	0		154884.9952	18949.21044	
34.5	7090.582	6.917641	7.686268	0	0	0		150477.9082	23563.96119	
35.5	7024.988	6.853647	7.615163	0	0	0		149085.8511	25021.61258	
36.5	6908.905	6.740395	7.489328	0	0	0		146622.3164	27601.23011	
37.5	6776.322	6.611046	7.345606	0	0	0		143808.6049	30547.52488	
38.5	6679.452	6.516539	7.240599	0	0	0		141752.8224	32700.17672	
39.5	6617.618	6.456213	7.17357	0	0	0		140440.5682	34074.26481	
40.5	7151.646	6.977216	3.356118	5.946836	0	0		0	15238.76753	
41.5	7778.922	7.589193	4.172087	5.946836	0	0		0	15238.76753	
42.5	7778.922	7.589193	4.172087	5.946836	0	0		0	15238.76753	
43.5	7778.922	7.589193	4.172087	5.946836	0	0		0	15238.76753	
44.5	7778.922	7.589193	4.172087	5.946836	0	0		0	15238.76753	
45.5	7778.922	7.589193	4.172087	5.946836	0	0		0	15238.76753	
46.5	7778.922	7.589193	4.172087	5.946836	0	0		0	15238.76753	
47.5	4679.408	4.565276	4.172087	0.900441	0	0		0	28377.12298	
48.5	4590.523	4.478559	4.172087	0.804089	0	0		0	25340.62309	
49.5	3714.926	3.624318	3.35618	0.67084	0	0		0	21141.30366	
50.5	4999.022	4.877094	3.356126	0.52633	1.536538	0		0	16587.12166	48423.51357
51.5	5547.698	5.412388	4.172087	0.380746	1.460931	0		0	11999.10199	46040.77215
52.5	5415.7	5.283609	4.172087	0.311735	1.386855	0		0	9824.221992	43706.28791
53.5	9682.262	9.44611	4.172087	0.311735	1.313922	6.797069		0	9824.221992	41407.83182

	[m3]	Volume/meter [m^3/m]						Ballast	Water Weight	Water Weight
Station	Buoyancy		Remora					Water	, CW	, WW
[m]	Total	Total	Only	CW	WW	PVs		[m3]	[m3]	[m3]
54.5	9835.03	9.595151	4.172087	0.311735	1.2423	7.067413		0	9824.221992	39150.68379
55.5	9780.999	9.542438	4.172087	0.311735	1.172015	7.067413		0	9824.221992	36935.68669
56.5	9727.897	9.490631	4.172087	0.311735	1.102939	7.067413		0	9824.221992	34758.77948
57.5	9675.765	9.439771	4.172087	0.311735	1.035125	7.067413		0	9824.221992	32621.64895
58.5	10283.98	10.03316	4.172087	0.311735	1.497487	7.396231		0	9824.221992	24363.87671
59.5	16338.08	15.93959	3.356204	0.311735	9.983449	7.601395		0	9824.221992	17055.05802
60.5	16338.17	15.93968	3.356091	0.311735	9.983688	7.601395		0	9824.221992	17055.46676
61.5	16964.85	16.55107	4.172087	0.311735	9.982882	7.601395		0	9824.221992	17054.0894
62.5	18015.68	17.57627	4.172087	0.311735	9.982882	8.968328		0	9824.221992	17054.0894
63.5	15181.33	14.81106	4.172087	0.311735	11.97291	0		0	9824.221992	20453.71937
64.5	12942.26	12.6266	4.172087	0.311735	9.545729	0		0	9824.221992	31587.2162
65.5	4974.305	4.852981	4.172087	0.311735	0.908379	0		0	9824.221992	28627.27095
66.5	4861.524	4.74295	4.172087	0.311735	0.786122	0		0	9824.221992	24774.39238
67.5	4755.529	4.639541	4.172087	0.311735	0.671223	0		0	9824.221992	21153.38671
68.5	4653.468	4.539969	4.172087	0.311735	0.560588	0		0	9824.221992	17666.75392
69.5	3805.608	3.712788	3.356167	0.311735	0.457418	0		0	9824.221992	14415.39468
70.5	3178.469	3.100945	2.830744	0.311735	0.303015	0		0	9824.221817	9549.432033
71.5	3370.734	3.288521	3.039162	0.311735	0.303015	0		34324.26563	9824.221992	9549.432208
72.5	3362.806	3.280786	3.039074	0.303229	0.303015	0		34356.95547	9556.153956	9549.432208
73.5	5176.292	5.050041	3.039162	2.278478	0.293515	0		34238.31536	8441.496329	9250.044388
74.5	6978.719	6.808506	3.039074	2.245302	2.280631	0		33570.26116	8423.283333	8509.323959
75.5	13941.73	13.60168	3.039162	2.214317	2.258107	7.601395		26583.36353	7704.1	7799.511474
76.5	13894	13.55512	3.037759	2.185526	2.236565	7.601395		26608.61914	6984.916667	7120.606935
77.5	13850.49	13.51268	3.037759	2.158927	2.216003	7.601395		26634.03744	6265.733333	6472.61034
78.5	13811.21	13.47435	3.039162	2.134521	2.196422	7.601395		26659.61844	5546.55	5855.521691
79.5	6570.307	6.410056	2.832155	2.112307	2.177822	0		33332.81945	4827.366667	5269.340986
80.5	10055.57	9.810315	6.624	2.104766	2.171584	0		127966.6289	4108.183333	5072.755467
81.5	9849.14	9.608917	8.505006	0	2.171569	0		166301.673	3389.910023	5072.265741
82.5	7684.798	7.497364	8.330404	0	0	0		163088.4892	5179.582133	5179.582133
83.5	7568.044	7.383458	8.203842	0	0	0		160610.7185	6476.844301	6476.844301
84.5	7437.811	7.256401	8.062667	0	0	0		157846.8718	7923.884457	7923.884457
85.5	7294.097	7.116192	7.90688	0	0	0		154796.9492	9520.7026	9520.7026
86.5	7136.903	6.962833	7.736481	0	0	0		151460.9505	11267.29873	11267.29873
87.5	6966.23	6.796322	7.551469	0	0	0		147838.876	13163.67285	13163.67285
88.5	6782.076	6.61666	7.351844	0	0	0		143930.7255	15209.82495	15209.82495
89.5	6595.982	6.435105	7.150116	0	0	0		139981.4013	17277.53396	17277.53396
90		0	0	0	0	0		0		
	3030830	2956.907								
		3030830								
		3056837	kg, weight per Dicks weight statement							
		0.991492								

Longitudinal Buoyancy Distribution-Upright



Longitudinal Buoyancy Distribution-Upright



NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-17
Mass Moment – Deployed
OTEC-2010-001

17 September 2010

Prepared for:

Naval Facilities Engineering Command
Naval Facilities Engineering Service Center (NFESC)
1100 23rd Avenue
Port Hueneme, CA 93043-4370
Attn: Mr. Brian Cable, Contracting Officer Representative

Prepared by:

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9500 Godwin Drive
Manassas, VA 20110

Distribution Statement A: Approved for public release; distribution is unlimited

APPENDIX 3.3.2.1.1-5

Remora Iteration 2.1 Calculation of Mass Moment of Inertia and Gyradii

Deployed Configuration

[Project]

LCG origin is uppermost corner, platform side (+ right)		Weight				LCG	VCG	TCG				
VCG origin is centerline of side view (+ up from platform)		(kg)	Margin	Total (kg)		(mm)	(mm)	(mm)		I_{xx}	I_{yy}	I_{zz}
TCG is centerline of back view (+ port up)										(kg-mm^2)	(kg-mm^2)	(kg-mm^2)
	SUMMARY OF WEIGHT GROUPS											
Group 1	Hull Structure	3559055	15	4092913		56217	5035	0		13987597498324100	13987821480368000	182659675902378
Group 2	Propulsion Machinery	0	15	0		0	0	0				
Group 3	Electrical Generation	0	15	0		0	0	0				
Group 4	Communications & Controls	0	15	0		0	0	0				
Group 5	Auxiliary Systems	3567518	15	4102645		55833	1399	0		11827328952730900	11840312086897300	80936674849694
Group 6	Outfit & Furnishings	0	15	0		0	0	0				
	Lightship (w/o margin)	**7126572**		**8195558**		**56025**	**3215**	**0**				
Group F	Variable Load	0	0	0		0	0	0				
Group F	Mission Ready Fuel Weight	0	0	0		0	0	0				
Group M	Design Margin											
	Full Load	**7126572**		**8195558**		~~**56025**~~	~~**3215**~~	~~**0**~~		25814926451055000	25828133567265400	263596350752072
						use CG from OTEC Iter 21 Wts AH36 v1						
										k_{xx}	k_{yy}	k_{zz}
									Gyradius (mm)	60186	60201	6082

LCG origin is uppermost corner, platform side (+ right) VCG origin is centerline of side view (+ up from platform) TCG is centerline of back view (+ port up)	Qty	Unit Wt (kg)	WEIGHT (kg)	LCG (mm)	VCG (mm)	TCG (mm)	I_{xx} (kg-mm^2)	I_{yy} (kg-mm^2)	I_{zz} (kg-mm^2)
GROUP 1 HULL									
110 Shell and Supporting Structure			1074959						
111 Shell Plating									
Upper Hull									
Fr 0-10	1	45212	52492	5000			3226070833333	3226070833333	2952675000000
Fr 10-40	1	203372	264356	25000			177614187500000	177614187500000	14870025000000
Center Tube Fr 0-10	1	7505	7505	5000			209123697917	209123697917	11726562500
Center Tube Fr 10-40	1	33692	33692	25000			23610721875000	23610721875000	52643750000
Top	1	16497	19737	0			277551562500	277551562500	555103125000
Middle Section									
Penstock									
Shell Plate Fr 40-50	1	1212	19036	45000			38807952071675	39241920833333	636806238342
Trans Bkhd Fr 40-50	1	24005	35145	45000			72120468750000	71461501171500	658969921500
Truss - Vertical Tubes									
Compt 6									
V1	1	9213	9213	45000	-5303	5303	18915411226317	18915411226317	518172452634
V2	1	9213	9213	45000	5303	5303	18915411226317	18915411226317	518172452634
V3	1	9213	9213	45000	-5303	-5303	18915411226317	18915411226317	518172452634
V4	1	9213	9213	45000	5303	-5303	18915411226317	18915411226317	518172452634
Compt 7									
V1	1	9213	9213	55000	-5303	5303	28128411226317	28128411226317	518172452634
V2	1	9213	9213	55000	5303	5303	28128411226317	28128411226317	518172452634
V3	1	9213	9213	55000	-5303	-5303	28128411226317	28128411226317	518172452634
V4	1	9213	9213	55000	5303	-5303	28128411226317	28128411226317	518172452634
Compt 8									
V1	1	9213	9213	65000	-5303	5303	39184011226317	39184011226317	518172452634
V2	1	9213	9213	65000	5303	5303	39184011226317	39184011226317	518172452634
V3	1	9213	9213	65000	-5303	-5303	39184011226317	39184011226317	518172452634
V4	1	9213	9213	65000	5303	-5303	39184011226317	39184011226317	518172452634
Compt 9									
V1	1	9213	9213	75000	-5303	5303	52082211226317	52082211226317	518172452634
V2	1	9213	9213	75000	5303	5303	52082211226317	52082211226317	518172452634
V3	1	9213	9213	75000	-5303	-5303	52082211226317	52082211226317	518172452634
V4	1	9213	9213	75000	5303	-5303	52082211226317	52082211226317	518172452634
Truss - Horizontal Tubes									
Compt 6									
H1	1	881	881	50000	0	5303	2227275313729	2202500000000	24775313729
H2	1	881	881	50000	5303	0	2202500000000	2227275313729	24775313729
H3	1	881	881	50000	0	-5303	2227275313729	2202500000000	24775313729
H4	1	881	881	50000	-5303	0	2202500000000	2227275313729	24775313729
Compt 7									

LCG origin is uppermost corner, platform side (+ right)																
VCG origin is centerline of side view (+ up from platform)									WEIGHT		LCG	VCG	TCG	I_{xx}	I_{yy}	I_{zz}
TCG is centerline of back view (+ port up)							Qty	Unit Wt (kg)	(kg)		(mm)	(mm)	(mm)	(kg-mm^2)	(kg-mm^2)	(kg-mm^2)
					H1		1	881	881		60000	0	5303	3196375313729	3171600000000	24775313729
					H2		1	881	881		60000	5303	0	3171600000000	3196375313729	24775313729
					H3		1	881	881		60000	0	-5303	3196375313729	3171600000000	24775313729
					H4		1	881	881		60000	-5303	0	3171600000000	3196375313729	24775313729
				Compt 8												
					H1		1	881	881		70000	0	5303	4341675313729	4316900000000	24775313729
					H2		1	881	881		70000	5303	0	4316900000000	4341675313729	24775313729
					H3		1	881	881		70000	0	-5303	4341675313729	4316900000000	24775313729
					H4		1	881	881		70000	-5303	0	4316900000000	4341675313729	24775313729
			Truss - Braces													
				Compt 6												
					B1		2	2296	4592		45000	0	5303	9427935346928	9298800000000	129135346928
					B2		2	2296	4592		45000	5303	0	9298800000000	9427935346928	129135346928
					B3		2	2296	4592		45000	0	-5303	9427935346928	9298800000000	129135346928
					B4		2	2296	4592		45000	-5303	0	9298800000000	9427935346928	129135346928
				Compt 7												
					B1		2	2296	4592		55000	0	5303	14019935346928	13890800000000	129135346928
					B2		2	2296	4592		55000	5303	0	13890800000000	14019935346928	129135346928
					B3		2	2296	4592		55000	0	-5303	14019935346928	13890800000000	129135346928
					B4		2	2296	4592		55000	-5303	0	13890800000000	14019935346928	129135346928
				Compt 8												
					B1		2	2296	4592		65000	0	5303	19530335346928	19401200000000	129135346928
					B2		2	2296	4592		65000	5303	0	19401200000000	19530335346928	129135346928
					B3		2	2296	4592		65000	0	-5303	19530335346928	19401200000000	129135346928
					B4		2	2296	4592		65000	-5303	0	19401200000000	19530335346928	129135346928
				Compt 9												
					B1		2	2296	4592		75000	0	5303	25959135346928	25830000000000	129135346928
					B2		2	2296	4592		75000	5303	0	25830000000000	25959135346928	129135346928
					B3		2	2296	4592		75000	0	-5303	25959135346928	25830000000000	129135346928
					B4		2	2296	4592		75000	-5303	0	25830000000000	25959135346928	129135346928
		Lower Hull														
			Fr 70.5-80				1	28611	46965		75250			266545680762303	267616354375000	1571107637303
			Fr 70.5-80 Transverse				1	23717	38575		75250			219266729166667	219265928413958	1085728413958
			Fr 80-85				1	45176	60632		82500			414508141666667	414508141666667	3410550000000
			Fr 85-90				1	45176	60352		87500			463893133333333	463893133333333	3394800000000
113	Inner Bottom															
114	Shell Appendages															
115	Stanchions															
116	Longitudinal Stiffeners															
		Upper Hull Plate Stiffeners														
			Fr 0-10				56	130								
			Fr 10-30				56	619								
			Fr 30-40				56	470								

LCG origin is uppermost corner, platform side (+ right)														
VCG origin is centerline of side view (+ up from platform)							WEIGHT		LCG	VCG	TCG	I_{xx}	I_{yy}	I_{zz}
TCG is centerline of back view (+ port up)						Qty	Unit Wt (kg)	(kg)	(mm)	(mm)	(mm)	(kg-mm^2)	(kg-mm^2)	(kg-mm^2)
		Mid-Section												
			Fr 40-50			32	557							
			Fr 40-50 Trans			20	557							
		Lower Hull Plate Stiffeners												
			Fr 70.5-80			21	874							
			Fr 70.5-80 Trans			17	874							
			Fr 80-85			56	276							
			Fr 85-90			56	271							
		UH Longitudinal Diagonal Frames												
			Compt 1			4	76							
			Compt 2			4	76							
			Compt 3			4	464							
			Compt 4			4	464							
			Compt 5			4	464							
		Bulkhead Stiffeners												
			Upper Hull											
				Top		18	180							
				Bkhd 1		18	180							
				Bkhd 2		18	180							
				Bkhd 3		18	255							
				Bkhd 4		18	433							
				Bkhd 5		18	502							
			UH Longitudinal Bkhd Stiffs											
				Fr 0-10		16	130							
				Fr 10-40		16	1411							
			UH Transverse Bkhd Stiffs											
				Fr 0-10		16	130							
				Fr 10-40		16	1411							
			Mid-Section											
				Bkhd 6		18	164							
			Lower Hull											
				Bkhd 7		18	173							
				Bkhd 8		18	380							
				Bkhd 9		18	398							
				Bkhd 10		18	382							
			LH Longitudinal Bkhd Stiffs											
				Fr 80-85		18	276							
				Fr 85-90		18	271							
			LH Transverse Bkhd Stiffs											
				Fr 80-85		18	276							
				Fr 85-90		18	271							
		Brackets				0.1	294338	29434	35000	7500	0	36056405000000	37712056250000	1655651250000
117	Transverse Framing													

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TCG is centerline of back view (+ port up)								Qty	Unit Wt (kg)	(kg)	(mm)	(mm)	(mm)	(kg-mm^2)	(kg-mm^2)	(kg-mm^2)
		Upper Hull														
			Fr 2.5					1	6007	6007	2500			191735105288	191735105288	337893750000
			Fr 7.5					1	6007	6007	7500			492085105288	492085105288	337893750000
			Fr 12.5					1	6007	6007	12500			1092785105288	1092785105288	337893750000
			Fr 15					1	6007	6007	15000			1505766355288	1505766355288	337893750000
			Fr 17.5					1	6007	6007	17500			1993835105288	1993835105288	337893750000
			Fr 20					1	6007	6007	20000			2556991355288	2556991355288	337893750000
			Fr 25					1	8843	8843	25000			5751020289600	5751020289600	497418750000
			Fr 27.5					1	8843	8843	27500			6911664039600	6911664039600	497418750000
			Fr 32.5					1	10725	10725	32500			11600129970000	11600129970000	603281250000
			Fr 35					1	10725	10725	35000			13406169026250	13406169026250	603281250000
			Fr 37.5					1	10725	10725	37500					
		Mid-Section														
			Fr 42.5					1	8777	8777	42500	9970	0	16072814983650	16072814983650	493706250000
			Fr 45					1	8777	8777	45000	9970	0	17992783733650	17992783733650	493706250000
			Fr 47.5					1	8777	8777	47500	9970	0	20022464983650	20022464983650	493706250000
		Lower Hull														
			Fr 73					1	11992	11992	73000	12875	0	63960241202762	63960241202762	344484999429
			Fr 75.5					1	11992	11992	75500	12875	0	68412271202762	68412271202762	344484999429
			Fr 82.5					1	19684	19684	82500	7500	0	134449618205000	134449618205000	1107225000000
			Fr 87.5					1	19684	19684	87500	7500	0	151181018205000	151181018205000	1107225000000
120	**Hull Structural Bulkheads (ex SS)**									635219						
121	Longitudinal Structural Bulkheads															
		Upper Hull														
			Fr 0-10					2	6001	14082	5000	7500	0	469400168984	515239843750	315378293984
			Fr 10-40					2	27005	76586	25000	7500	0	53610202067822	48753770052083	1715209359489
		Lower Hull														
			Fr 80-85					1	14403	19371	82500	7500	0	131884226452825	132247431250000	733980749700
			Fr 85-90					1	14403	19281	87500	7500	0	147660326446075	148021843750000	730570586700
122	Transverse Structural Bulkheads															
		Upper Hull														
			Bkhd 1					1	16497	19737	5000	7500	0	770976562500	770976562500	555103125000
			Bkhd 2					1	16497	19737	10000	7500	0	2251251562500	2251251562500	555103125000
			Bkhd 3					1	24745	29335	22500	7500	0	15263367187500	15263367187500	825046875000
			Bkhd 4					1	24745	32539	32500	7500	0	34826898437500	34826898437500	915159375000
			Bkhd 5					1	24745	33781	40000	7500	0	54524645312500	54524645312500	950090625000
			Transverse													
				Fr 0-10				2	6001	14082	5000	7500	0	515239843750	469400168984	315378293984
				Fr 10-40				2	27005	76586	25000	7500	0	53859503385417	53610202067822	1715209359489
		UH Longitudinal Diagonal Frames														
			Compt 1													
				D1				1	1500	1576	2500	-3094	3094	33350331203	28220141781	14980227245
				D2				1	1500	1576	2500	3094	3094	33350331203	28220141781	14980227245

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VCG origin is centerline of side view (+ up from platform)										WEIGHT		LCG	VCG	TCG	I_{xx}	I_{yy}	I_{zz}
TCG is centerline of back view (+ port up)								Qty	Unit Wt (kg)	(kg)		(mm)	(mm)	(mm)	(kg-mm^2)	(kg-mm^2)	(kg-mm^2)
				D3			1	1500		1576	2500	3094	-3094	33350331203	28220141781	14980227245
				D4			1	1500		1576	2500	-3094	-3094	33350331203	28220141781	14980227245
			Compt 2														
				D1			1	1500		1576	7500	-3094	3094	112150331203	107020141781	93780227245
				D2			1	1500		1576	7500	3094	3094	112150331203	107020141781	93780227245
				D3			1	1500		1576	7500	3094	-3094	112150331203	107020141781	93780227245
				D4			1	1500		1576	7500	-3094	-3094	112150331203	107020141781	93780227245
			Compt 3														
				D1			1	6751		7215	16250	-3094	3094	2091710589865	2068224456545	1928697460430
				D2			1	6751		7215	16250	3094	3094	2091710589865	2068224456545	1928697460430
				D3			1	6751		7215	16250	3094	-3094	2091710589865	2068224456545	1928697460430
				D4			1	6751		7215	16250	-3094	-3094	2091710589865	2068224456545	1928697460430
			Compt 4														
				D1			1	6751		7215	26250	-3094	3094	5097960589865	5074474456545	4995072460430
				D2			1	6751		7215	26250	3094	3094	5097960589865	5074474456545	4995072460430
				D3			1	6751		7215	26250	3094	-3094	5097960589865	5074474456545	4995072460430
				D4			1	6751		7215	26250	-3094	-3094	5097960589865	5074474456545	4995072460430
			Compt 5														
				D1			1	6751		7215	35000	-3094	3094	8991054339865	8967568206545	8861861522930
				D2			1	6751		7215	35000	3094	3094	8991054339865	8967568206545	8861861522930
				D3			1	6751		7215	35000	3094	-3094	8991054339865	8967568206545	8861861522930
				D4			1	6751		7215	35000	-3094	-3094	8991054339865	8967568206545	8861861522930
		Mid-Section															
			Bkhd 6				1	6874		9826	50000	12000	0	24703178125000	24703178125000	276356250000
		Lower Hull															
			Bkhd 7				1	6634		9748	70500	1625	0	48449997799856	48449997742523	219939330179
			Bkhd 8				1	33936		40776	80000	7500	0	261539812500000	261539812500000	1146825000000
			Bkhd 9				1	33936		41100	85000	7500	0	297525468750000	297525468750000	1155937500000
			Bkhd 10				1	33936		40812	90000	7500	0	331151118750000	331151118750000	1147837500000
			Transverse														
				Fr 80-85			1	14403		19371	82500	7500	0	132247431250000	131884226452825	363207702825
				Fr 85-90			1	14403		19281	87500	7500	0	148021843750000	147660326446075	361520196075
123	Trunks & Enclosures																
130	**Structural Decks (ex SS)**								0								
131	Lower Hull Decks																
132	Spar Wet Decks																
136	Upper Hull Deck																
140	**Hull Platforms & Flats**								0								
141	1st Platform																
149	Flats																

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TCG is centerline of back view (+ port up)		Qty	Unit Wt (kg)		(kg)		(mm)	(mm)	(mm)	(kg-mm^2)	(kg-mm^2)	(kg-mm^2)
150	**Deckhouse Structure**				0							
151	Deckhouse Structure to First Level											
160	**Special Structures**				88800							
161	Structural Castings, Forgings, Weldments											
	Platform Mounts											
	PM1	1	18000			18000	2000	-5300	5300	102000000000	103260000000	1024500000000
	PM2	1	18000			18000	2000	-5300	-5300	102000000000	103260000000	1024500000000
	PM3	1	18000			18000	38000	-5300	5300	26022000000000	26023260000000	1024500000000
	PM4	1	18000			18000	38000	-5300	-5300	26022000000000	26023260000000	1024500000000
163	Sea Chests											
166	Sponsons											
	Skirt Assembly	1	16800			16800	100000	7500	0	168350000000000	168350000000000	420000000000
167	Hull Structural Closures											
	Lower Deck WT Hatches											
	Upper Deck WT Hatches											
168	Deckhouse Structural Closures											
169	Special Purpose Closures											
170	**Masts, Kingposts, Service Platforms**				0							
171	Masts, Towers, Tetrapods											
172	Kingposts & Support Frames											
180	**Foundations**				99312							
181	Hull Structure Foundations											
	Platform Mount Foundations	4				0						
	Skirt Foundation	0.1	16800			1680	90000	7500	0	13629140000000	13629140000000	42000000000
182	Propulsion Plant Foundations											
183	Electrical Plant Foundations											
184	Command & Surveillance Foundations											
185	Auxiliary Systems Foundations											
	Condenser Foundation	0.1	170000			17000	43500	4470	0	32168250000000	32507925300000	339675300000
	Evaporator Foundation	0.1	250000			25000	60500	7660	0	91506250000000	92973140000000	1466890000000
	NH3 Buffer Tank Foundation	0.1	15157			1516	54000	3830	0	4419781200000	4442014851730	22233651730
	NH3 Module Foundation	0.1	17230			1723	73100	10530	0	9207040030000	9398087820700	191047790700
	NH3 Demister Foundation	0.1	12156			1216	53850	8000	0	3525024231000	3602822631000	77798400000
	WW Pump Foundation	0.1	50000			5000	75000	7780	0	28125000000000	28427642000000	302642000000
	CW Pump Foundation	0.1	40000			4000	77000	3200	0	23716000000000	23756960000000	40960000000
	WW Piping Foundation	0.1	106405			10641	55000	7780	0	32187512500000	32831564940200	644052440200
	CW Piping Foundation	0.1	114376			11438	63100	3200	0	45540062536000	45657183560000	117121024000
	NH3 Piping Foundation	0.1	201000			20100	52000	10200	0	54350400000000	56441604000000	2091204000000
186	Outfit & Furnishing Foundations											

LCG origin is uppermost corner, platform side (+ right)														
VCG origin is centerline of side view (+ up from platform)							WEIGHT		LCG	VCG	TCG	I_{xx}	I_{yy}	I_{zz}
TCG is centerline of back view (+ port up)					Qty	Unit Wt (kg)	(kg)		(mm)	(mm)	(mm)	(kg-mm^2)	(kg-mm^2)	(kg-mm^2)
190	**Special Purpose Systems**						1660764							
191	Ballast (Fixed or Fluid)													
		Upper Hull Water			0.3	1752326		525698	36500	7500	0	709900118712500	707753519362500	14785250625000
		Lower Hull Water			0.6	1796863		1078118	85000	7500	0	7813546451562500	7813546451562500	30322063125000
		LH Extra Tank			0	335944		0	75250	1625	0	0	0	0
199	Hull Repair Parts & Special Tools													
		Welding			0.030	1898290		56949	42660	6350				
	GROUP 1 TOTAL						3559055	3559055	56217	5035	0	62691	62691	7164

LCG origin is uppermost corner, platform side (+ right) VCG origin is centerline of side view (+ up from platform) TCG is centerline of back view (+ port up)							Qty	Unit Wt (kg)	WEIGHT (kg)	LCG (mm)	VCG (mm)	TCG (mm)	I_{xx} (kg-mm^2)	I_{yy} (kg-mm^2)	I_{zz} (kg-mm^2)
GROUP 5	**AUXILIARY SYSTEMS**														
500	**Auxiliary Systems, General**														
501	General Arrangement - Auxiliary Systems Drawings														
502	Auxiliary Machinery														
503	Pumps														
504	Instruments & Instrument Boards														
505	General Piping Requirements														
506	Overflows, Air Escapes & Sounding Tubes														
507	Machinery & Piping Designation and Marking														
508	Thermal Insulation for Piping & Machinery														
509	Thermal Insulation for Vent & A/C Ducts														
510	**Climate Control**								0						
511	Compartment Heating System														
512	Ventilation System														
	Mist Eliminators														
	Fans														
	Piping, Vents, Plenums														
	Dampers														
	Goose Necks														
513	Machinery Space Ventilation System														
514	Air-Conditioning System														
516	Refrigeration Systems														
520	**Sea Water Systems**								854062						
521	Firemain & Flushing System														
524	Auxiliary Seawater System														
	Cold Water System														
		Condenser													
			Heat Exchangers												
				CHX1			1	100000	100000	43500	-2900	2500	189864458333333	189864458333333	1928250000000
				CHX2			1	100000	100000	43500	-2900	-2500	189456125000000	189456125000000	1928250000000
				Misc											
		Seawater Pump					1	40000	40000	77000	-2900	0	237503383333333	237503383333333	458900000000
		Hardware													
			Misc												
		Trunking													
			Intake				1	32668	32668	38000	-5300	0	47330496453150	47330496453150	1037445026300
			Converger				1	17090	17090	46500	-2900	0	37020277890625	37020277890625	196065025000

LCG origin is uppermost corner, platform side (+ right)															
VCG origin is centerline of side view (+ up from platform)									WEIGHT		LCG	VCG	TCG	I_{xx}	I_{yy}	I_{zz}
TCG is centerline of back view (+ port up)								Qty	Unit Wt (kg)	(kg)	(mm)	(mm)	(mm)	(kg-mm^2)	(kg-mm^2)	(kg-mm^2)
				Mid Section				1	36283	36283	57700	-2900	0	121767607503750	121767607503750	416256717500
				Discharge				1	28335	28335	87000	-2900	0	214917297707312	214917297707312	360297234375
			Screen													
				Inner												
				Outer												
		Warm Water System														
			Evaporator													
				Heat Exchangers												
					WHX1			1	112100	112100	60500	800	2550	410811842416667	410659760083333	1079055916667
					WHX2			1	112100	112100	60500	800	-2550	410811842416667	410659760083333	1079055916667
					WHX3			1	56050	56050	60500	3900	1750	205343191916667	205306198916667	1076954041667
					WHX4			1	56050	56050	60500	3900	-1750	205343191916667	205306198916667	1076954041667
				Misc												
			Seawater Pump					1	50000	50000	77000	1500	0	296877750000000	296877750000000	293000000000
			Hardware													
				Misc												
			Trunking													
				Intake				1	49582	49582	60000	2100	0	179072375798333	178770917238333	743564726667
				Converger				1	27800	27800	64600	1500	0	116219534697917	116218757166667	271317864583
				Discharge				1	29023	29023	87000	1500	0	220133828770521	220133828770521	190263904375
			Screen													
				Inner				1								
				Outer				1								
526	Scuppers & Deck Drains															
528	Plumbing Drainage															
529	Drainage & Ballasting System															
		Ballast System														
			Level Sensors													
			Pumps													
			Piping, Hose													
			Valves													
		Bilge System														
			Level Sensors					18	2	40	22000	7500				
			Pumps					18	154	2772	22000	7500				
			Piping, Hose					9	423	3807	22000	7500				
			Valves							0	22000	7500				
			Misc					0.1	3620	362	22000	7500				
530	**Fresh Water Systems**									0						
540	**Fuels & Lubricants, Handling & Storage**									0						
541	Ship Fuel & Fuel Compensating System															

LCG origin is uppermost corner, platform side (+ right)												
VCG origin is centerline of side view (+ up from platform)					WEIGHT	LCG	VCG	TCG	I_{xx}	I_{yy}	I_{zz}
TCG is centerline of back view (+ port up)		Qty	Unit Wt (kg)	(kg)		(mm)	(mm)	(mm)	(kg-mm^2)	(kg-mm^2)	(kg-mm^2)
550	**Air, Gas & Misc. Fluid Systems**			245544							
551	Compressed Air Systems										
555	Fire Extinguishing Systems										
	Fire Suppression										
	CO2	0	354		0						
	CO2 Tank	0	5019		0						
	Piping	0	292		0						
	Misc	0	5665		0						
	Portable Firefighting Equipment										
556	Hydraulic Fluid System										
558	NH3 System										
	Buffer Tanks										
	NBT1	1	7579		7579	52280	-1780	-4780	20734252913183	20734252913183	209023514700
	NBT2	1	7579		7579	52280	-1780	4780	20734252913183	20734252913183	209023514700
	Demisters										
	ND1	1	6078		6078	53850	2460	-5480	17643405805000	17643405805000	225384396000
	ND2	1	6078		6078	53850	2460	5480	17643405805000	17643405805000	225384396000
	Pump Module										
	Pump										
	NP1	1	8615		8615	52000	4790	-2770	23341642531250	23341642531250	274189605000
	NP2	1	8615		8615	52000	4790	2770	23341642531250	23341642531250	274189605000
	Motor	2									
	Enclosure										
	Piping	1	134000		134000	52000	10200	0	362336000000000	376277360000000	13941360000000
	Brackets	1	67000		67000	52000	10200	0	181168000000000	188138680000000	6970680000000
	Flanges	1			0	52000	10200				
	Valves	1			0	52000	10200				
	Hardware										
	Misc										
560	**Ship Control Systems**			0							
561	Steering & Diving Control Systems										
562	Rudder										
565	Trim & Heel Systems (Surface Ships)										
567	Strut & Foil Systems										
568	Maneuvering Systems										
570	**Underway Replenishment Systems**			0							
572	Ship Stores & Equipment Handling Systems										
580	**Mechanical Handling Systems**			0							
581	Anchor Handling & Stowage Systems										
582	Mooring & Towing Systems										
	Cleats										

LCG origin is uppermost corner, platform side (+ right)														
VCG origin is centerline of side view (+ up from platform)								WEIGHT		LCG	VCG	TCG	I_{xx}	I_{yy}	I_{zz}
TCG is centerline of back view (+ port up)							Qty	Unit Wt (kg)	(kg)		(mm)	(mm)	(mm)	(kg-mm^2)	(kg-mm^2)	(kg-mm^2)
		Bitts														
		Eyes														
		Ropes, Lines														
583	Boats, Boat Handling & Stowage Systems															
585	Elevating & Retracting Gear															
589	Misc Mechanical Handling Systems															
590	**Special Purpose Systems**								2467912							
592	Swimmer & Diver Support and Protection Systems															
593	Environmental Pollution Control Systems															
595	Towing, Launching & Handling for Underwater Systems															
596	Handling System for Diver and Submersible Vehicles															
598	Auxiliary Systems Operating Fluids															
		Cold Seawater														
			CHX1				1	41697		41697	43500	-2900	2500	79119597095625	79119597095625	707650211250
			CHX2				1	41697		41697	43500	-2900	-2500	79119597095625	79119597095625	707650211250
			Intake				1	205000		205000	38000	-5300	0	296822945281250	296822945281250	6134340562500
			Converger				1	87638		87638	46500	-2900	0	189742089710937	189742089710937	934905751875
			Mid Section				1	185423		185423	57700	-2900	0	622147126444375	622147126444375	1843336398750
			pump				1	39514		39514	77000	-2900	0	234587464319583	234587464319583	392818552500
			Discharge				1	127305		127305	87000	-2900	0	965454871565531	965454871565531	1344698845313
		Warm Seawater														
			Penstock				1	905075		905075	45000	4500	0	1857289322916670	1850785484135830	27440546556667
			WHX1				1	34338		34338	60500	800	2550	125838153835000	125791568615000	85387732300
			WHX2				1	34338		34338	60500	800	-2550	125838153835000	125791568615000	85212608500
			WHX3				1	17167		17167	60500	3900	1750	62892534801667	62881204581667	16262585217
			WHX4				1	17167		17167	60500	3900	-1750	62892534801667	62881204581667	16202500717
			Intake				1	276750		276750	60000	2100	0	999521600625000	997838960625000	2930441175000
			Converger				1	274085		274085	64600	1500	0	1145828459269010	1145820793454170	2058689550677
			pump				1	37413		37413	77000	1500	0	222107979982500	222107979982500	151709715000
			Discharge				1	127305		127305	87000	1500	0	965446714497656	965446714497656	560500045313
		NH3					1	16000		16000	52000	8145	0	43264000000000	44325456400000	1061456400000
599	Auxiliary Systems Repair Parts & Special Tools															
	TOTAL GROUP 5								3567518	3567518	55833	1399	0	57578	57610	4763

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-18
Towing and Docking Conops
OTEC-2010-001

17 September 2010

Prepared for:

Naval Facilities Engineering Command
Naval Facilities Engineering Service Center (NFESC)
1100 23rd Avenue
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Prepared by:

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Distribution Statement A: Approved for public release; distribution is unlimited

APPENDIX 3.3.2.1.1-6

Remora Iteration 2.1 Towing and Docking CONOP

Towing and Docking CONOP

It is assumed the Remora will be positioned in the dry dock with the warm water ductwork side down and the cold water side up. By having the Remora positioned warm water side down the coldwater ductwork can remain dry, unflooded, because both down flooding points remain above the waterline during undocking and tow-out to the OTEC platform.

An auxiliary removable soft tank is required to float the Remora from the dry dock. The removable soft tank is 8m long and 15m diameter. The removable soft tank can be constructed as a half cylinder, to keep the weight down, provided the Remora heels no greater than 15 degrees.

Ballast tank #1, as shown in Figure 1, must be filled to a height of 7.1m prior to submerging the dry dock and floating the Remora. Note, this tank must be filled prior to floating the Remora and not allowed to free flood.

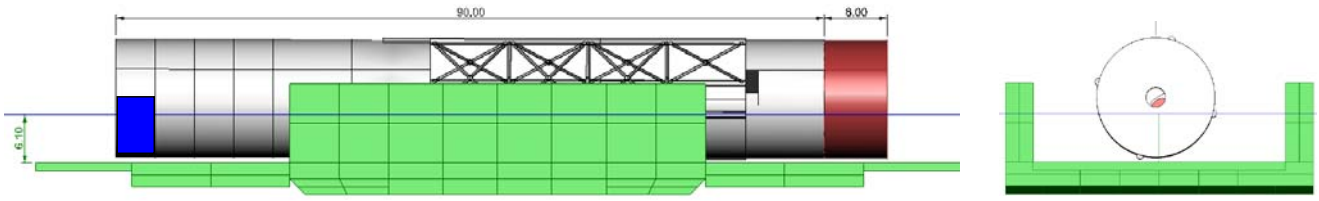


Figure 1. Remora in PSI dry dock

Once the Remora is floated from the drydock, Ballast tank #2 must be filled to a height of 7.1m, further submerging the top side of the Remora. Note, this tank can be allowed to free flood to the water line and the remaining volume pumped.

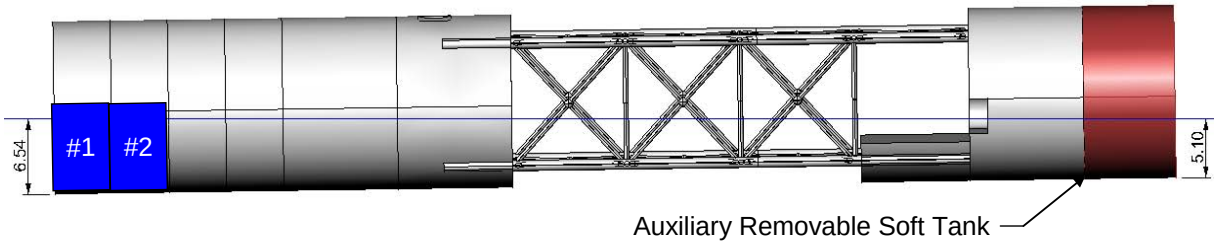


Figure 2. Remora just after float

At this point in time the auxiliary removable soft tank should be removed, see Figure 3, this is the tow configuration. A means of taking the load off the connection between Remora and auxiliary soft tank will be required. Once the tank is removed a draft change of 4 meters will be experienced.

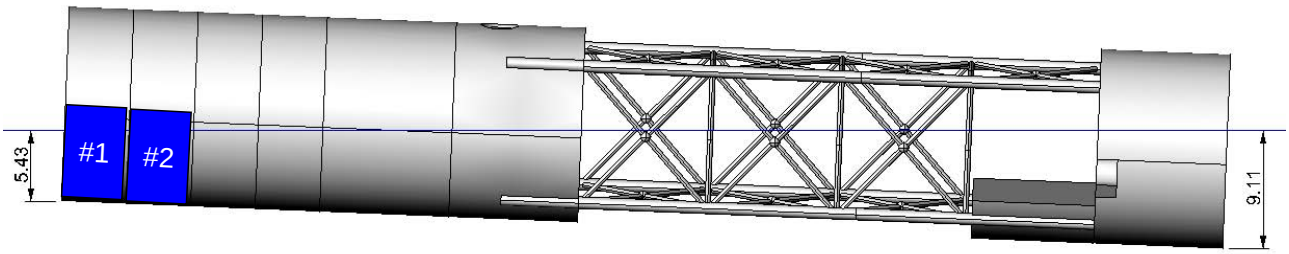


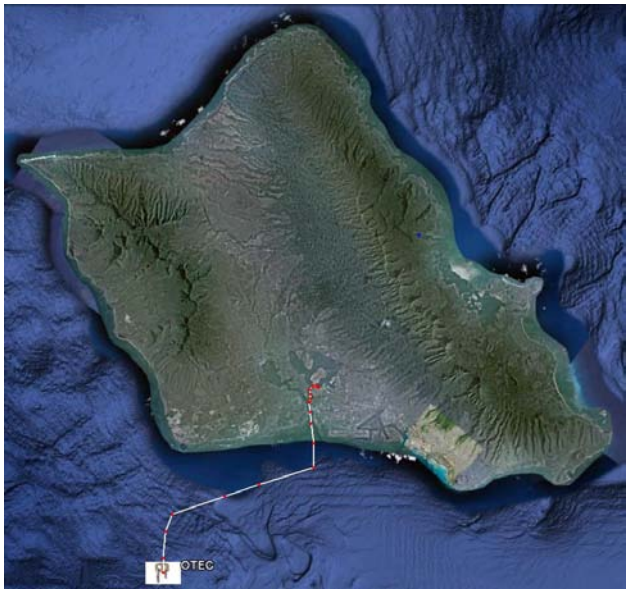
Figure 3. Remora with Auxiliary Soft Tank Removed

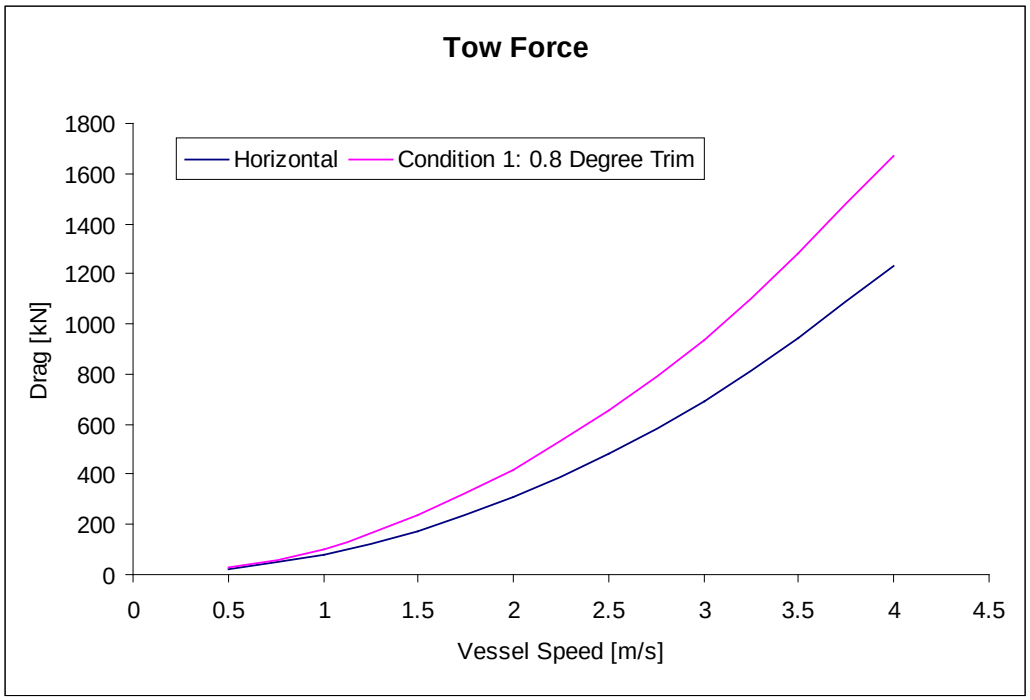
The Remora will be towed 22.5 miles, from Pier 41 Honolulu Hawaii to the OTEC site south of Barbers Point, location Lat: 21 deg 10' 8.9" N Long: 158 deg 7' 21.36" W. The entire tow should take just over 5-1/2 hours at a speed of 4 knots depending on how long it takes to get out of the harbor. One to 3 hours is required to remove Remora from the dry dock and remove auxiliary soft tank.



If an option of performing the final assembly and integration occurs at dry dock #4 at Pearl Harbor is elected a tow of 20 miles will be required taking 5 hours. The 1 to 3 hour evolution of removing from the drydock and removing auxiliary soft tank is probably not required.

The tow force is a function of the geometry complexity and the trim during the tow. A tow force of about 500kN is required at a tow speed of 4 knots.





Once at the OTEC site the Remora will be upended and secured to the platform.

Reverse the above procedure to float the Remora onto the PSI dry dock.

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-19
Weight and Buoyancy – Towing

OTEC-2010-001

17 September 2010

Prepared for:

Naval Facilities Engineering Command
Naval Facilities Engineering Service Center (NFESC)
1100 23rd Avenue
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Distribution Statement A: Approved for public release; distribution is unlimited

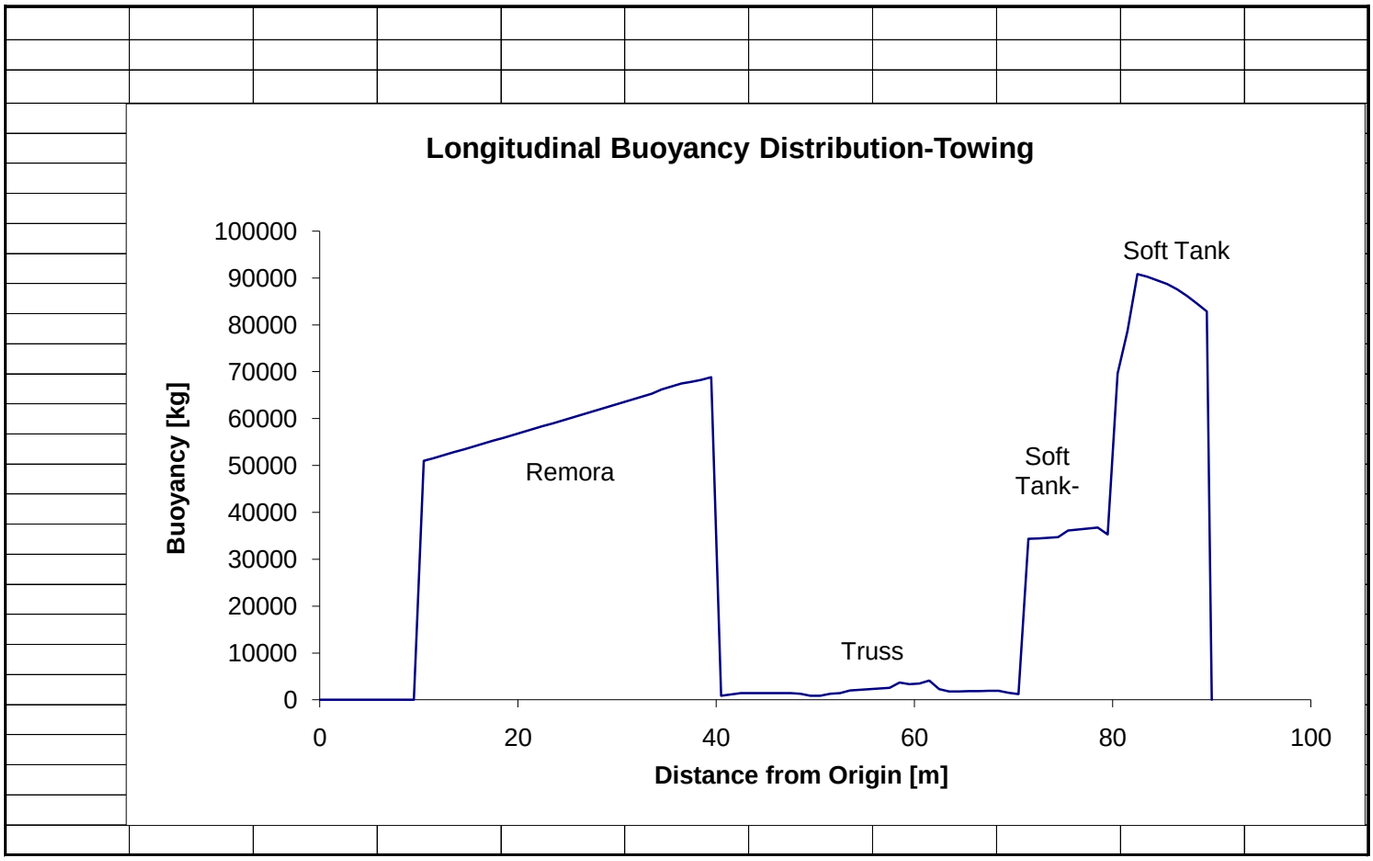
APPENDIX 3.3.2.1.1-7

Remora Iteration 2.1 Detailed Calculation of Longitudinal Buoyancy and Weight Distribution

Towing Configuration

Sectional Area [m^2]			
Station	Total	Buoyancy	
[m]	[m^2]	[m^3]	
0	0	0	
0.5	0	0	
1.5	0	0	
2.5	0	0	
3.5	0	0	
4.5	0	0	
5.5	0	0	
6.5	0	0	
7.5	0	0	
8.5	0	0	
9.5	0	0	
10.5	49.73689	50980.31	
11.5	50.33139	51589.67	
12.5	50.92723	52200.42	
13.5	51.52438	52812.49	
14.5	52.12276	53425.83	
15.5	52.72235	54040.41	
16.5	53.32317	54656.25	
17.5	53.9252	55273.33	
18.5	54.52843	55891.64	
19.5	55.13278	56511.1	
20.5	55.73823	57131.69	
21.5	56.34477	57753.39	
22.5	56.9524	58376.21	
23.5	57.56111	59000.14	
24.5	58.17086	59625.13	
25.5	58.78158	60251.12	
26.5	59.39327	60878.11	
27.5	60.00593	61506.08	
28.5	60.61955	62135.04	
29.5	61.23411	62764.96	
30.5	61.84956	63395.79	
31.5	62.46585	64027.49	
32.5	63.07832	64655.28	
33.5	63.69285	65285.17	
34.5	64.63146	66247.25	
35.5	65.25764	66889.08	
36.5	65.87798	67524.93	
37.5	66.21429	67869.65	
38.5	66.63959	68305.58	
39.5	67.17576	68855.16	
40.5	0.837084	858.0109	
41.5	1.161281	1190.313	
42.5	1.428182	1463.887	
43.5	1.428182	1463.887	
44.5	1.428182	1463.887	
45.5	1.428182	1463.887	
46.5	1.428182	1463.887	
47.5	1.428182	1463.887	

Sectional Area [m^2]			
Station	Total	Buoyancy	
[m]	[m^2]	[m^3]	
48.5	1.238341	1269.3	
49.5	0.837107	858.0351	
50.5	0.837083	858.0101	
51.5	1.280871	1312.893	
52.5	1.428182	1463.887	
53.5	1.967549	2016.738	
54.5	2.126188	2179.343	
55.5	2.237401	2293.336	
56.5	2.357405	2416.34	
57.5	2.484387	2546.497	
58.5	3.576108	3665.51	
59.5	3.256133	3337.536	
60.5	3.386692	3471.359	
61.5	4.016366	4116.776	
62.5	2.262221	2318.777	
63.5	1.715861	1758.758	
64.5	1.754446	1798.307	
65.5	1.793045	1837.871	
66.5	1.831325	1877.109	
67.5	1.868947	1915.671	
68.5	1.905549	1953.188	
69.5	1.470976	1507.751	
70.5	1.184862	1214.484	
71.5	33.4929	34330.22	
72.5	33.61316	34453.48	
73.5	33.7343	34577.66	
74.5	33.85279	34699.11	
75.5	35.26457	36146.19	
76.5	35.46599	36352.64	
77.5	35.66633	36557.99	
78.5	35.86485	36761.47	
79.5	34.40047	35260.49	
80.5	67.91124	69609.03	
81.5	76.75858	78677.54	
82.5	88.64269	90858.76	
83.5	88.03675	90237.67	
84.5	87.32824	89511.45	
85.5	86.55455	88718.41	
86.5	85.44411	87580.22	
87.5	84.07382	86175.67	
88.5	82.47521	84537.09	
89.5	80.85054	82871.81	
90	0	0	
		3026595	kg


Longitudinal Buoyancy Distribution-Towing
Buoyancy [kg]
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
0
20
40
60
80
100
Distance from Origin [m]
Remora
Truss
Soft
Tank-
Soft Tank

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-20
Upending CONOPS
OTEC-2010-001

17 September 2010

Prepared for:

Naval Facilities Engineering Command
Naval Facilities Engineering Service Center (NFESC)
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Attn: Mr. Brian Cable, Contracting Officer Representative

Prepared by:

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9500 Godwin Drive
Manassas, VA 20110

Distribution Statement A: Approved for public release; distribution is unlimited

APPENDIX 3.3.2.1.1-8

Remora Iteration 2.1 Upending CONOPS

Figure 1 shows the Remora as configured for the tow from Pier 41 to the OTEC site off Barbers Point.

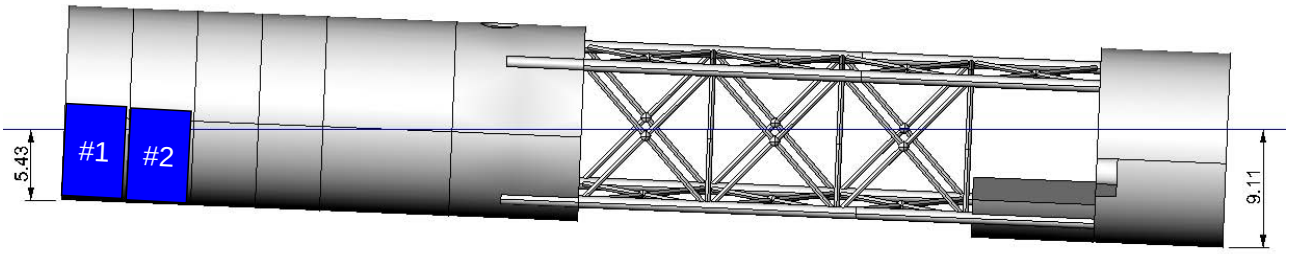


Figure 1. Remora Tow Configuration to OTEC Site

Once on site near the OTEC platform the Remora will begin the upending process. As the first step of the upending process, ballast tank #1 will be emptied and take on the orientation shown in Figure 2. Due to the shorter moment arm to ballast tank #2, by emptying ballast tank #1 first the remora will take on a greater trim angle than if ballast tank #2 were emptied first.

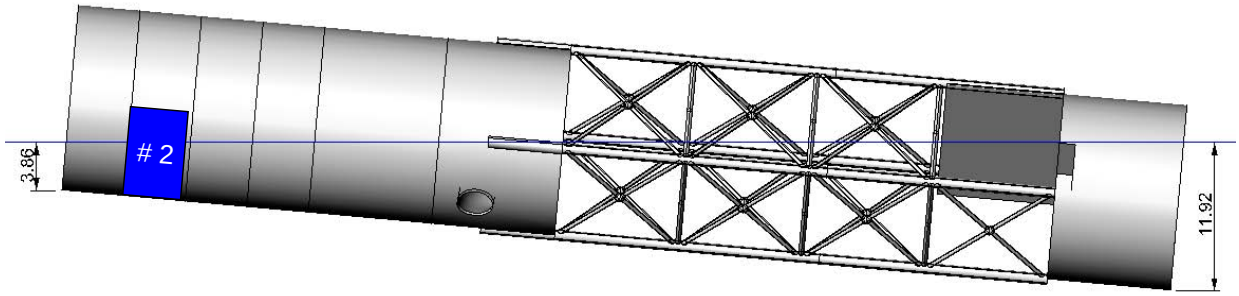


Figure 2. Remora Orientation after Emptying Ballast Tank #1

Because of the cylindrical shape, the remora has little to no restoring moment upon roll. Because there is little to no restoring roll moment, the remora is extremely sensitive and will have a tendency to roll during the deballasting process. In the currently modeled configuration the cold water system wants to rotate down due to the pump cutouts in the soft tank. This could change as the complexity of the hydrostatics model matures.

Ballast tank #2 will be emptied after ballast tank #1 has been emptied taking on the orientation as shown in Figure 3.

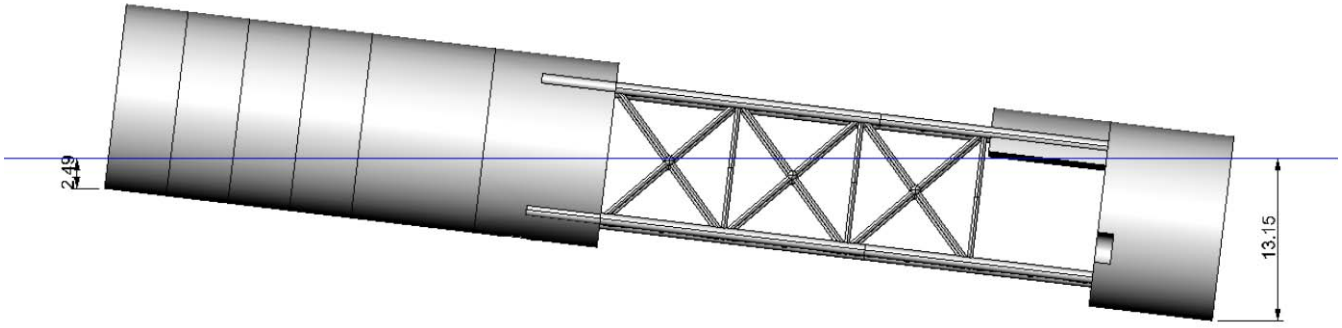


Figure 3. Remora Orientation after Emptying Ballast Tanks #1 and #2

At this point in time the upper soft tank is almost completely out of the water and not much benefit is gained when allowed to free flood as shown in Figure 4.

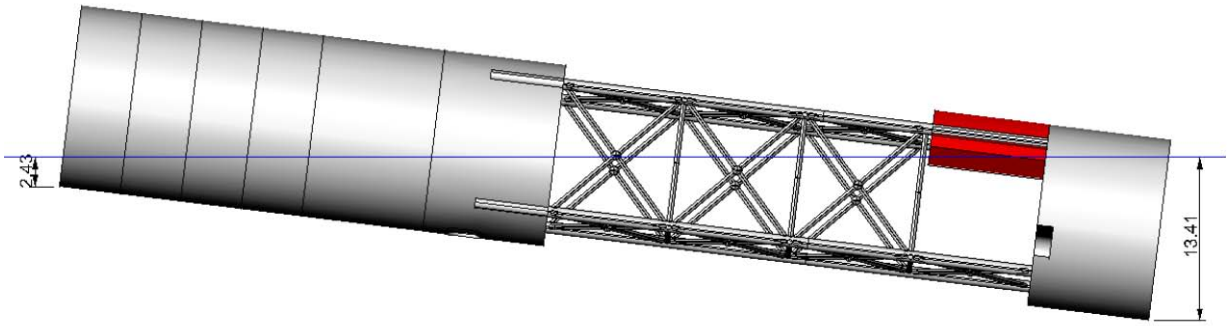


Figure 4. Remora Orientation after allowing Upper Soft Tank to Flood

Figure 5 shows the orientation of the Remora after the lower soft tank is allowed to free flood. The neutrally buoyant lightship upright draft is 69.34 meters at a weight of 3400750 kg. Ballast tank #3, located in the lower 10m of the hard tank will need to be flooded 3.6m, 637mt to obtain a Remora draft of 73 m.

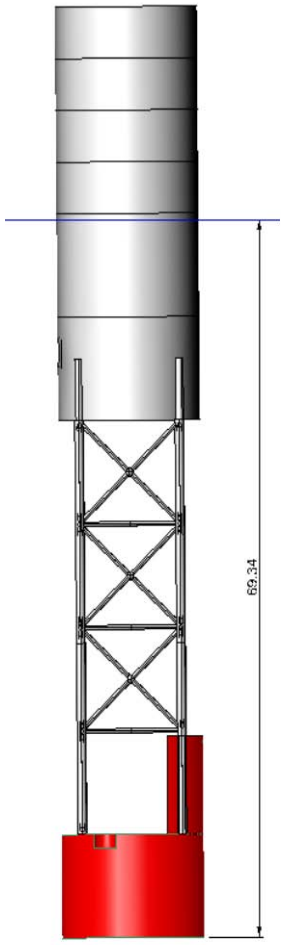


Figure 5. Remora In Upright Orientation, Lightship Draft of 69.34 meters.

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-21
Wave Interactions – 100 MW
OTEC-2010-001

17 September 2010

Prepared for:

Naval Facilities Engineering Command
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APPENDIX 3.3.2.1.1-9

Wave-Current Interactions for the 100 MW OTEC Plant

David Kring, Navatek, Ltd., July 22, 2010

Wave-Current Interactions for the 100 MW OTEC Plant

David Kring, Navatek, Ltd., July 22, 2010

Executive Summary

The ship seakeeping code AEGIR was used to look at the effect of a 5 knot current on the 100 MW OTEC Platform wave forces. WAMIT, a zero speed code, can only include current through the use of a shift in the frequency of encounter.

Results for heave added mass between showed little difference between the approximate method and the exact description of the current in AEGIR. However, there were some significant differences in the wave damping forces.

Consideration of the effective Froude number and reduced frequencies indicate that significant interactions should be expected in a current of 5 knots. At 5 knots, the critical reduced frequency is encountered, where the group velocity of the radiated waves travels at the same speed as the current. At 2 knots, the critical frequency would not be encountered, so WAMIT would be more suitable.

The result for wave damping is only a preliminary finding. The forward speed solution for the bluff cylinders hasn't been completely verified and there are still some issues with transient effects and gridding for AEGIR. Further work may be needed to conclusively establish the wave-current interaction. Also, this study only considers the interaction of waves, and the viscous effects from the current need to be studied separately. Nonlinear effects could also be examined in a future study.

Introduction

This is an initial investigation into the effects of ocean currents on the wave forces acting on the OTEC platform through the use of a potential-flow, wave-body interaction code called AEGIR. Current effects due to viscosity could be considered separately for the OTEC platform through the Morison assumption or other means.

The OTEC platform may encounter ocean currents up to 5 knots. Previous to this study, current was not included in the hydrodynamic analysis for wave radiation and diffraction forces. The code used for the analysis, WAMIT, is an industry standard for potential flow hydrodynamics, but it is a linear, frequency-domain, zero-speed code. An offshoot of the WAMIT research is the code AEGIR which can simulate time-domain ship motions with forward speed and

nonlinear effects. This forward-speed capability can also be used to simulate a platform in a current.

A common means to include current in zero-speed codes such as WAMIT has been to use a shift in the effective encounter frequency. Here, the results for a given incident wave period can be approximated in a current of speed U through a shift of frequency of encounter. The frequency of encounter is related to the absolute frequency by:

$$\omega_e = \omega_0 - Uk\cos(\beta)$$

where,

ω_e = encounter frequency
ω_0 = absolute, incident wave frequency
k = incident wave number
β = incident wave heading

For ship seakeeping, where the ship is moving into a head sea, the wave heading is defined as β=180 degrees. This yields an encounter frequency that is higher than the incident wave frequency.

For the OTEC platform in currents as high as 5 knots, it is not clear if this simple encounter shift assumption is valid. The purpose of this study is to apply a method that includes a formulation of the current in the free surface condition. This should help guide future analysis of the OTEC platform.

The scope of the study has been limited to a baseline 100 MW OTEC design without the cold water pipe or Remoras attached. These additional structures could be included in a later engineering analysis, but for now it is sufficient at this point to examine currents on the bare platform. A relative comparison of wave radiation forces with and without forward speed effects has been conducted. Wave diffraction forces were not computed in this scope of the work, but wave radiation damping will be a reasonable indicator of the current effects according to the Haskind Relation. This initial investigation only examined a minimal set of sensitivity tests on the wave forces in a current.

The results have been computed using the time-domain, forward-speed code AEGIR. AEGIR is a three-dimensional, potential-flow, Rankine Boundary Element Method used primarily for ship resistance and seakeeping. AEGIR and WAMIT, developed at the same group in MIT, share a similar Boundary Element Method (BEM). Although there are some important technical

differences, the core BEMs both use a geometry-independent, high-order approach. Beyond the BEM though, there are some fundamental differences between the two codes. WAMIT is a frequency-domain solution with no forward speed effects. Elements are placed only on the wetted hull surface and the wave Green function is limited to linear theory. AEGIR, a Rankine method, also applies boundary elements to the free surface domain. While this adds degrees of freedom and computational cost, it does allow for flexibility. AEGIR can simulate both linear and nonlinear free surface conditions and also solve in the time-domain.

WAMIT wave radiation forces, added mass and damping, were obtained for the 100 MW platform from Houston Offshore at a number of wave frequencies. These results are included below as a point of comparison. A contribution from Cold Water Pipe was included in the WAMIT results so the comparison is not for exact, but it's still useful as a benchmark. Previous studies have shown very close comparison between convergent solutions for AEGIR and WAMIT when the same geometry is used. The time-domain results from AEGIR have been transformed to the frequency-domain for comparison to WAMIT.

The most important comparison in this study will be the relative difference between AEGIR results with and without current. The results of AEGIR using the exact formulation for current will also be compared to the results from the encounter-frequency shift hypothesis.

Geometry: 100 MW OTEC Platform, Bare Hull

The CAD representation, shown in Figure 1 below, was recreated by Navatek from a set of electronic drawings received from John Halkyard. The port side, relative to a current U travelling from positive to negative on the x-axis, was developed. Along a current from that direction, there is a plane of port-starboard symmetry about the y-z plane.

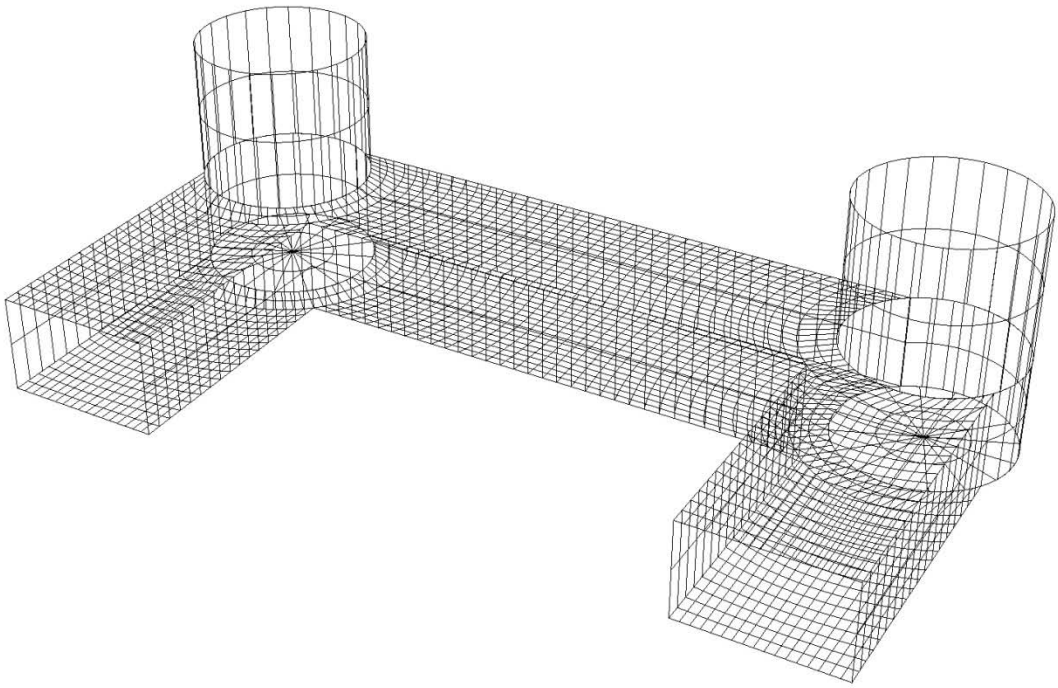


Figure 1: 100 MW OTEC Platform. Wireframe of CAD geometry, port side shown.

Within this CAD representation there are 34 separate Non-Uniform Rational B-Spline (NURBS) patches. Each patch has a varying number of basis functions of at least 3rd degree. The commercial CAD package, Rhinoceros, was used to generate the geometry. The resulting CAD representation is used directly in AEGIR. AEGIR uses the OpenNURBS library to translate the CAD information and makes no approximation of the NURBS geometry within its hydrodynamic integrations. AEGIR has a native geometry engine to evaluate and manipulate the NURBS surfaces.

Motions are not being computed, only wave radiation forces, so the inertial properties of the platform were not needed for this study.

AEGIR Verification

The first necessary task for the study was to identify the number of high-order elements and the time-step size needed to ensure numerical accuracy. A series of spatial and temporal sensitivity tests were run to establish convergence using the linear version of AEGIR. The results below in show the convergence in space and time for the time-history of the heave radiation force. This force includes both added mass and damping.

This AEGIR test case was for an 8 second period with 1-m amplitude wave, forced heave motion with zero forward speed. The linear forces can be scaled directly by wave amplitude.

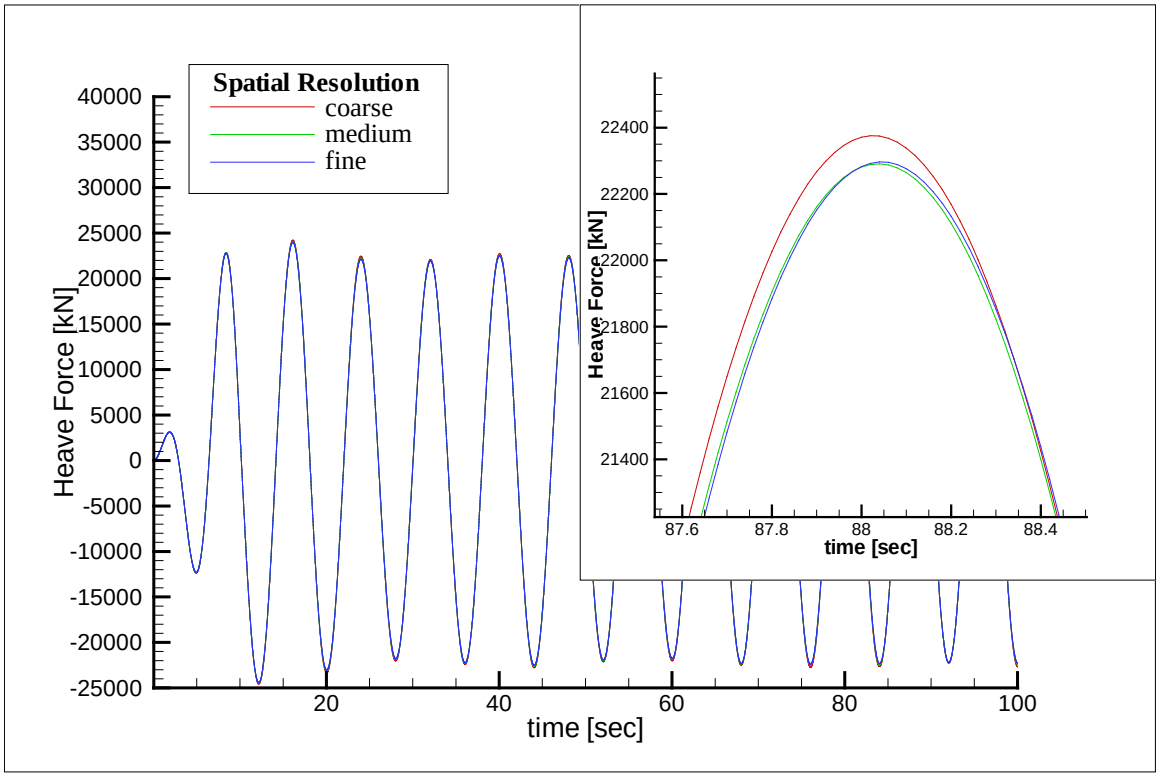


Figure 2: Spatial convergence of the heave force for heave radiation at an 8-second period, 1m amplitude and zero forward speed. The inset window is a magnification of one peak.

For the spatial resolution in Figure 2 the coarse, medium, and fine grids had approximately 5000, 6000, and 7000 quadratic elements respectively. One high-order quadratic element is roughly equivalent to nine flat panels based on local error analysis. The time history shows some transient behavior from the start at 0 seconds to about 40 seconds and then achieves a steady-state oscillation. The spatial convergence is good for this particular test case.

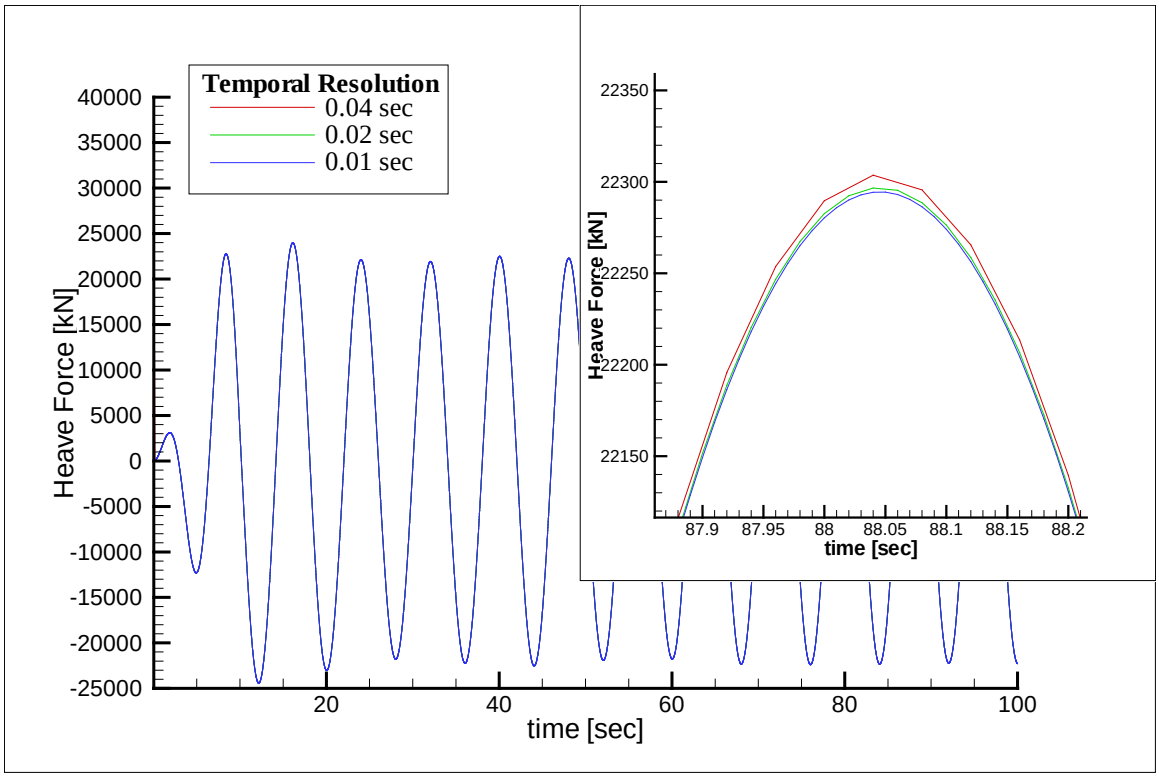


Figure 3: Temporal convergence of the heave force for heave radiation at an 8 second period, 1m amplitude and zero forward speed. The inset window is a magnification of one peak.

The temporal resolution shown in Figure 3 is good for this test case with time-step sizes of 0.04, 0.02, and 0.01 seconds. At 0.04 seconds, there are 200 time-steps per period in this case. Numerical stability can be achieved at much larger time steps, up to about 0.2 seconds. However, 0.04 seconds is required to for about 1% relative accuracy in the forces.

Two different free-surface domain sizes, of 500m and 1000m total width were also tested. These results for these domains were nearly identical for the 8 second wave, which is approximately 100m long. Generally, the domain has to roughly one wave length long to prevent numerical reflections. With the 1000m domain, a wave period of 20 seconds can be adequately captured. For longer waves, the Froude-Krylov hypothesis may be valid, so it may not be necessary to have very large domains in the final engineering analysis.

The results of this verification test look good, but this is a limited test. There has not been as rigorous testing over all possibly wavelengths and at all current speeds. The initial results have shown some sensitivity of the surge radiation forces in the 5 knot current, so only the heave results will be reported at this point. Further research would be useful to ensure that the code is robust for this type of platform in all conditions.

The quality of the forward speed results may have some serious issues based on the preliminary runs. AEGIR was developed for forward speed with ships in mind. The bluff shapes of a

platform in a current pose some new challenges in terms of robust gridding. Also, the domain-size issues will be different than zero speed. Within the scope of this study, not much time was available to thoroughly address these issues, which places a serious limit on the certainty of the results.

Another issue are transients in the time-domain solution. While the transients are mild in this zero-speed test case, initial results for surge radiation in 5 knot current showed some very strong transient behavior. Further work would need to be done to ensure the transients don't contaminate the understanding of the relative effect of current in the free surface formulation.

Benchmark vs WAMIT

A number of previous tests have compared AEGIR and WAMIT results on offshore platforms such as semi-submersibles. These have shown very close agreement where the CAD geometry is identical. An example of a previous benchmark is shown in Figure 4 below.

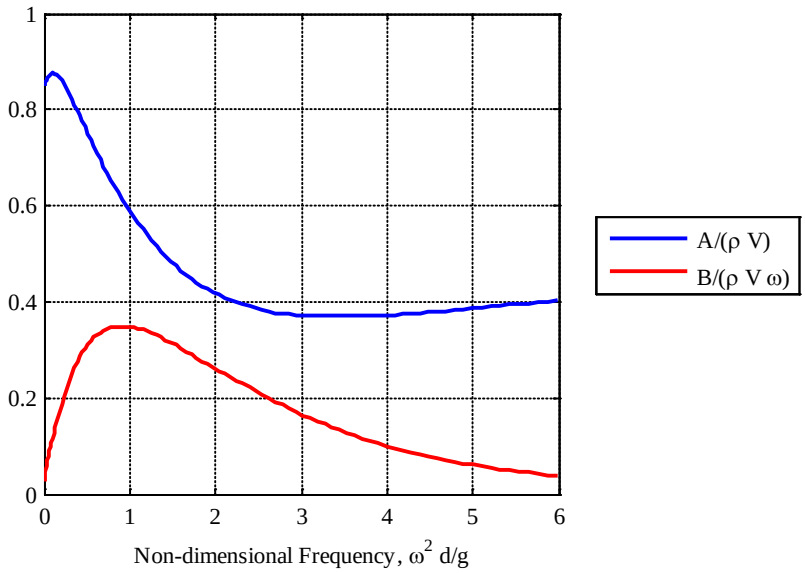


Figure 4: Heave coefficients for a floating sphere. WAMIT and AEGIR show agreement to a high precision with no apparent graphical difference.

For this simple floating sphere example there is no appreciable difference. For a more realistic semi-submersible with 8 columns and 2 pontoons, AEGIR and WAMIT v6.0 agreed to within 4 decimal places. This is not surprising since the two codes share very similar numerical methods.

The benchmark between AEGIR and WAMIT for a notional 100 MW OTEC platform is not so exact. The CAD files were recreated at Navatek based off electronic drawings. There may have been some differences in detail or dimensions in the platform run in AEGIR and that run in WAMIT by Houston Offshore. The displacements reported between AEGIR and WAMIT did not match for instance. Houston Offshore possibly included the Cold Water Pipe in their WAMIT runs or made some correction to the radiation coefficients to account for that extra structure.

The comparison of heave added mass and damping across a number of periods is shown in the figures below for WAMIT and AEGIR at zero forward speed.

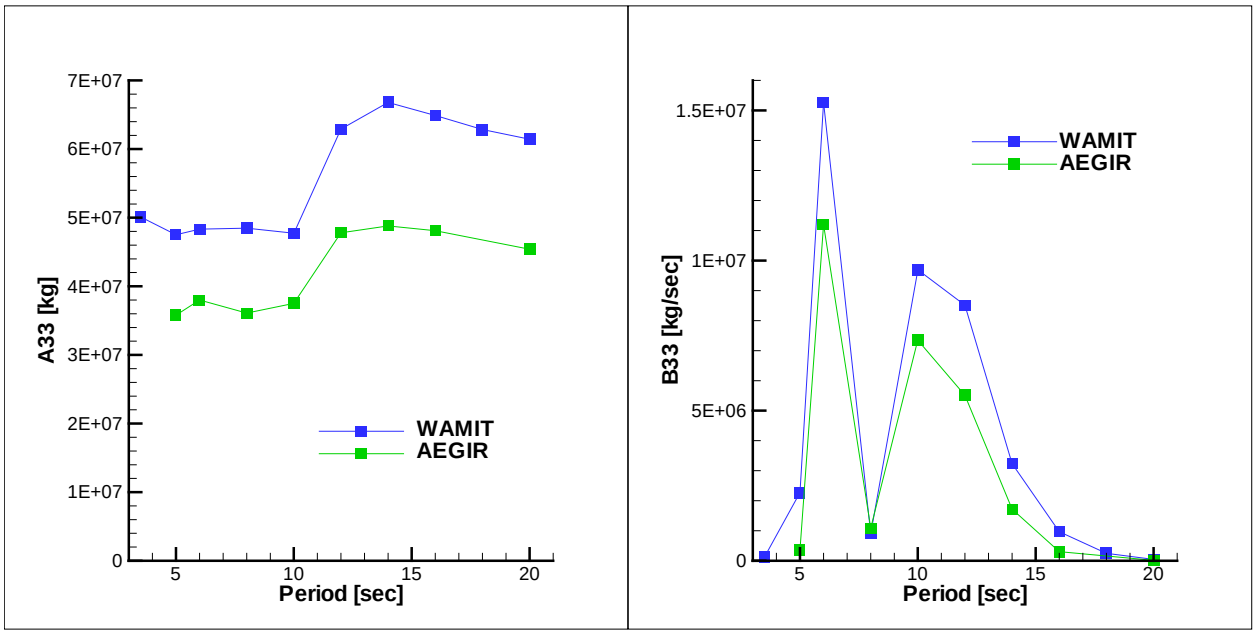


Figure 5: Comparison between WAMIT and AEGIR for heave radiation. AEGIR was run for the bare hull 100MW platform. WAMIT had a correction for the Cold Water Pipe.

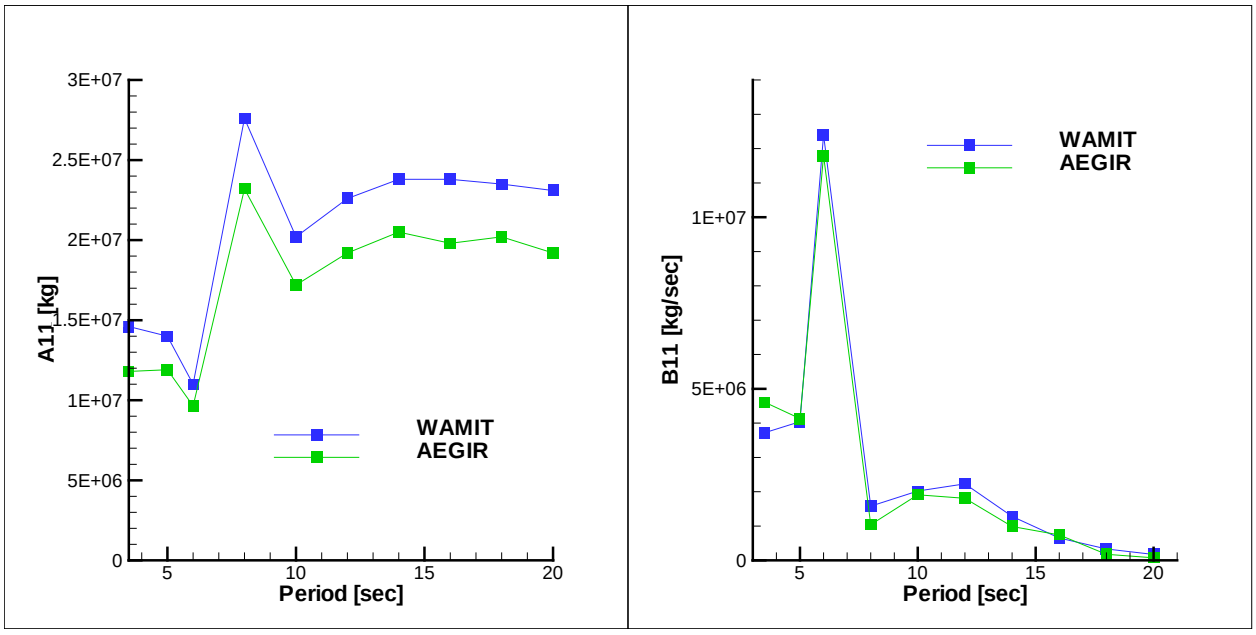


Figure 6: Comparison between WAMIT and AEGIR for surge radiation. AEGIR was run for the bare hull 100MW platform. WAMIT had a correction for the Cold Water Pipe.

Given previous benchmark agreement between WAMIT and AEGIR, it is reasonable to assume that the differences shown in Figures 5 and 6 stem from some difference in the geometry set up or some correction for the Cold Water Pipe. Since the Cold Water Pipe has a larger projected area in the heave direction, this CWP correction could also explain why the surge results are somewhat closer.

The main purpose of this study is to gauge the effect of current. That will depend on the relative difference between AEGIR runs and zero speed and in current, so this absolute difference between WAMIT and AEGIR can be pinned down at some later date. The resolution of this would require closer communication with Houston Offshore to determine the exact details of their problem set up.

Effect of Current

To gauge the effect of current three results based on AEGIR are compared:

1. 0 knots … baseline run at zero speed represent no current.
2. 5 knots, encounter-frequency shift … the zero-speed results are shifted to the 5 knot encounter frequency, similar to what could be done with WAMIT.
3. 5 knots, exact current model … the platform is run at a forward speed of 5 knots.

Running AEGIR at 5 knots of forward speed in calm water is identical to the case of a platform with zero speed over ground in a 5 knot current. The free surface conditions used in AEGIR

account for the forward speed effects exactly. The exact free surface conditions are expressed separately as a kinematic and dynamic condition.

The kinematic free surface condition is:

$$\left[\frac{\partial}{\partial t}-\left(\vec{U}+\frac{\partial \vec{x}}{\partial t}\right)\cdot\nabla\right]\zeta=\left(1+\nabla\zeta\cdot\nabla\zeta\right)\phi_z-\nabla\varphi\cdot\nabla\zeta \qquad \text{on } z=\zeta$$

and the dynamic free surface condition is:

$$\left[\frac{\partial}{\partial t}-\left(\vec{U}+\frac{\partial \vec{x}}{\partial t}\right)\cdot\nabla\right]\varphi=-g\zeta-\frac{1}{2}\nabla\varphi\cdot\nabla\varphi+\frac{1}{2}\left(1+\nabla\zeta\cdot\nabla\zeta\right)\phi_z^{\,2} \qquad \text{on } z=\zeta$$

where,

$\vec{U}$ = mean velocity = (U,0,0) with a current U in this case
$\vec{\mathrm{x}}$ = reference point for Zahkarov formulation
ζ = wave elevation
ϕ = volume potential
φ = surface potential, $\varphi(\mathrm{u},\mathrm{v},\mathrm{t})=\phi(\vec{\mathrm{x}}(\mathrm{u},\mathrm{v}),\mathrm{t})$

This is a Zakharov form for the fully-nonlinear free surface conditions in the time-domain. While the fully nonlinear form may be important for wave runup effects and some other extreme events that could impact the OTEC platform, the current work only used a linearized solution of the equations expressed on the z=0 plane. In the linear formulation based on small wave steepness, though, no further approximation is made for the current. Nonlinear studies could be a part of future work.

More details on the AEGIR formulation and previous work can be found in Kring (2004).

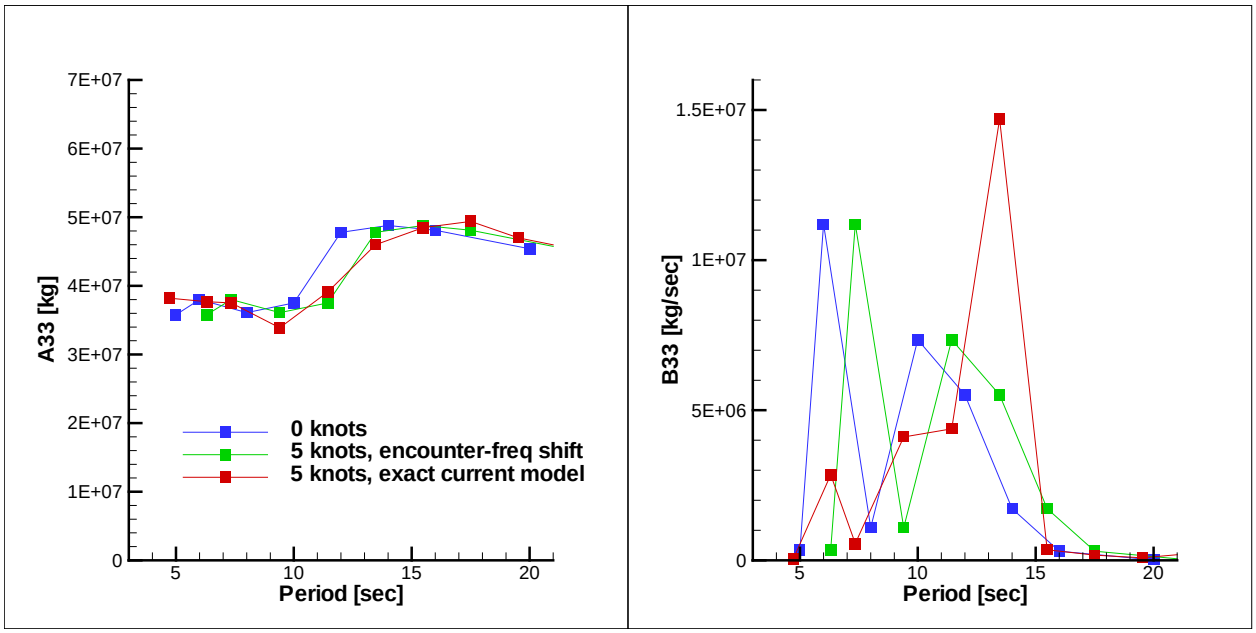


Figure 7: Effect of current in the heave radiation forces for the 100 MW OTEC platform. The radiation forces are plotted against the absolute period.

Figure 7 above compares the heave added mass and damping at no current to the case with 5 knots of current. The approximate encounter-frequency shift method is shown along with the results for the exact current formulation.

The heave added mass shows little difference between the approximate encounter frequency shift method and the exact current formulation. This would justify the use of the method with WAMIT. However, there is a pronounced difference between the wave damping results, which would indicate that the WAMIT could not be used in the 5 knot current.

The 5 knot current equates to a Froude number, $Fn = U / \sqrt{gD}$, near 0.2 based on the diameter of one column in the platform. The reduced frequency, $\tau = U\omega / g$, an important guide to the unsteady wave pattern, is 0.16, at an encounter period of 10 seconds.. Both of these values are reasonable high and forward speed effects would be noticeable for an equivalent ship. It could be reasonable to expect that the wave damping, and the related wave excitation, could be affected by the current. At this reduced frequency, the wave pattern will be offset significantly from the concentric zero-speed pattern. At an encounter frequency of 6.6 seconds, which is within the range of interest, the reduced frequency hits the critical $\tau = 0.25$ value where the waves being generated by the motion of the platform travel at 5 knots. At this point, the encounter-frequency shift method should be very suspect.

While the exact current formulation can be expected to show differences to the more approximate method, two major caveats need to be stated about these initial AEGIR results for forward speed. First, there are significant transient effects in the time history of the forces. The

surge radiation forces were not presented because this was a very significant problem. Near the 6 seconds encounter period, the solution never achieved a steady-state solution, probably due to the presence of the $\tau = 0.25$ critical frequency. Second, the wave patterns for the forward speed results showed some possible artificial behavior. While the spatial and temporal convergence tests showed excellent verification for zero speed, the forward speed results have not been studied so thoroughly. Also, the bluff cylindrical geometry may be causing some distortion of the free surface grid, which was originally developed for relatively slender ships.

Conclusion

The verification tests and benchmarking of AEGIR versus WAMIT at zero speeds shows good agreement between the codes in no current. The differences for the OTEC platform should be explained by differences in the geometry setup and Cold Water Pipe representation that can be cleared up with some further work.

The considerations of Froude number and the reduced frequencies for this platform do indicate that the simple encounter-frequency shift could be invalid for the OTEC platform in 5 knots, and the initial AEGIR results do show difference for the wave damping. However, further work verification and improvements need to be done to ensure that the AEGIR results in a current are accurate.

The presence of the critical $\tau = 0.25$ at 5 knots could be a serious concern in the design of the platform. At 2 knots, the values for the reduced frequency would be much lower and the encounter-frequency shift method would probably be justified.

Recommendations relating to current include:

1. Identify the maximum current for design considerations: if 5 knots is probable, then current effects will be important, at 2 knots the approximate method would be sufficient.

2. Revisit the AEGIR solution for 5 knots to ensure that the solution is accurate. At present there a low confidence level in the 5 knot results.

Another recommendation is to use AEGIR to examine possible nonlinear effects in steep waves.

References

Kring, D.C., Milewski, W.M., and Fine, N.E., “Validation of a NURBS-Based BEM for Multihull Ship Seakeeping”, 25th Symposium on Naval Hydrodynamics, St. John’s, Newfoundland and Labrador, Canada, 2004.

Kring, D.C., Korsemeyer, F.T., Singer, J., and White, J., “Analyzing Mobile Offshore Bases using Accelerated Boundary Element Methods.”, *J. of Marine Structures*, 13, pp 301-313, 2000.

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-22
LAMP Study
OTEC-2010-001

17 September 2010

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Distribution Statement A: Approved for public release; distribution is unlimited

APPENDIX 3.3.2.1.1-10

OTEC LAMP Relative Motion Study

Christopher Hart, Navatek, Ltd., June 6, 2010

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OTEC LAMP Relative Motion Study

Summary

SAIC's Large Amplitude Motion Program (LAMP) was used to study the relative motions between the OTEC Platform and Remora in close proximity over a range of sea states and headings. This program is a 3D time domain potential flow multi-body seakeeping program. The modeling included many assumptions such as the platform was free floating with no cold water pipe or moorings and the remora was also modeled as un-tethered. Initial modeling allowed for a six degree of freedom motion of each body, however, this caused the relative position of each body to change with time. So the final modeling was run with freedom of each body in Heave, pitch and roll but constrained in surge sway and yaw. Sea states were modeled as short crested (meaning they had a spreading function that distributed the energy about the primary wave direction to provide a more realistic wave excitation than simple long crested waves). For each combination of sea state and heading, a 10 minute run was simulated. Statistics were tabled for each run about each body's center of gravity, and then also post-processed at particular points of interest (such as a potential contact point near the base of the remora). Although runs were made at various headings to the waves, it appears that the most significant motion responses are excited primarily by the longer period swells regardless of heading. This is due to the fact that the natural periods of each body are so large compared to the typical wave periods seen in that area. However, since the Froude Kryloff and hydrostatic pressures were modeled as fully non-linear, the simulation would have captured any significant non-linear motion which might have been excited by shorter period waves. Motion time histories were converted to animations of the two body motion for selected cases and will be provided separately. It should be noted that for ease of creating the animations, the waves as shown are simply the incident wave field (i.e. the undisturbed incoming waves) depicted as unaffected by the presence of each body. However the computed and animated motion responses of each body fully take into account the reflected, radiated and diffracted waves interacting between bodies. That said, it was interesting that the heading was less important to the relative motions than the sea state in which it was operating. In other words for most cases the motions were not greatly affected by whether the remora was shielded from the waves by the platform or whether it was up-wave of the platform. This should have positive implications for the full scale rigging.

Wave and Sea State Info

Model Properties and Set up

Natural Periods and Damping

Calculated

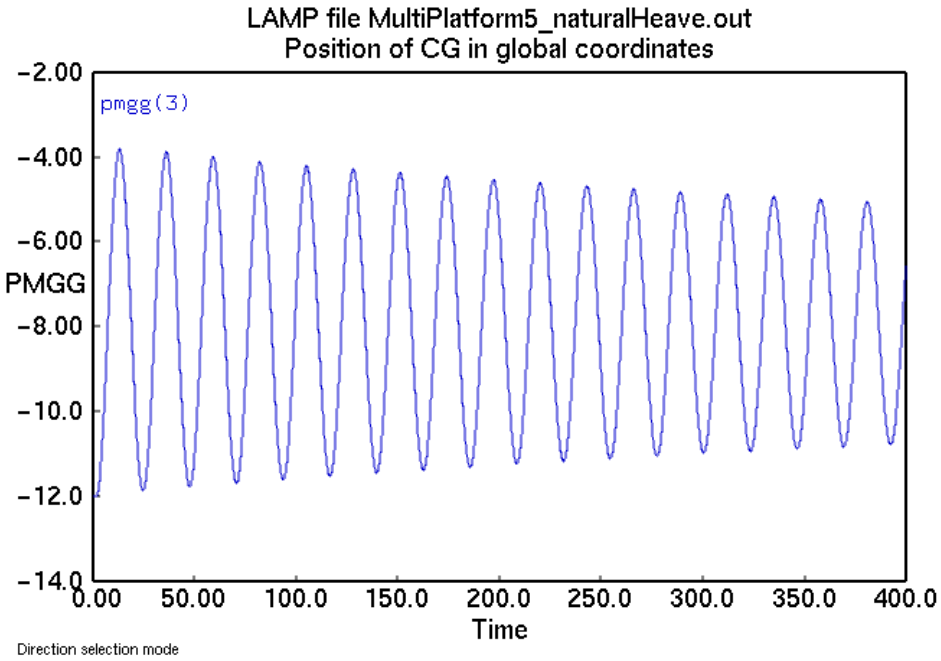
Natural Period Check					
Undamped Natural Period Calc		Platform	Platform	Remora	Remora
Volume	V	18593.2	18593.2	5467.847	5468.847
Waterplane Area	Awp	380	380	177	177
Added Mass Coef	A'33	0.5	1	0.5	1
Added Mass Coef	A'55	0.5	1	0.5	1
GML = GMT	GML	4.78	4.78	11	11
Length or beam	L	60	60	15	15
Gyradii, m	Kp	26.6	26.6	60.4	60.4
Gyradii, % of L	Kp'	0.44	0.44	4.03	4.03
Heave Period, s	**T_z**	*17.2*	*19.8*	*13.7*	*15.8*
Roll&Pitch Per. ,s	**T_roll&pitch**	*45.9*	*60.2*	*37.1*	*37.6*

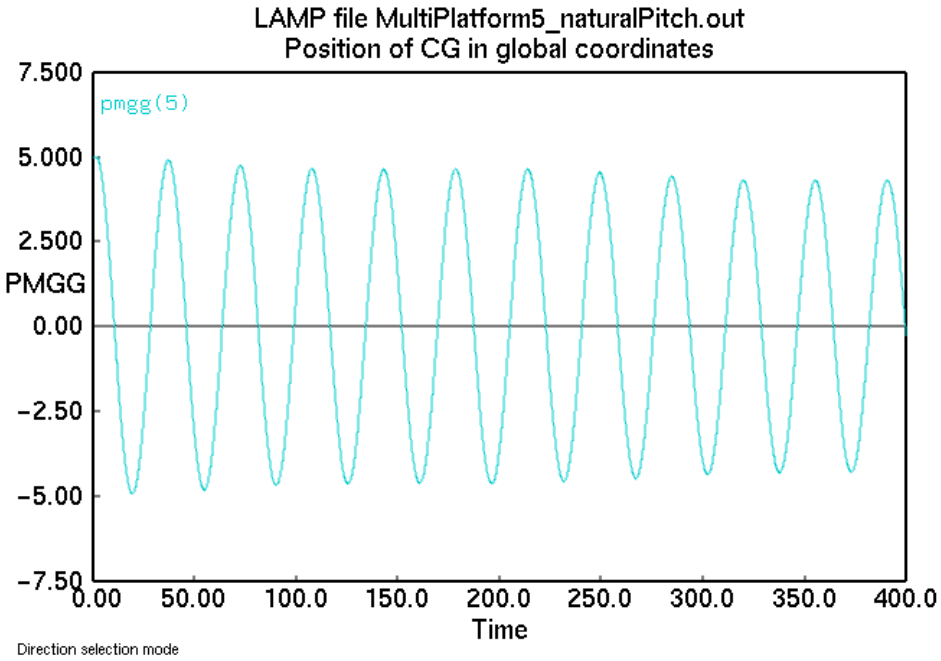
Motion Statistics

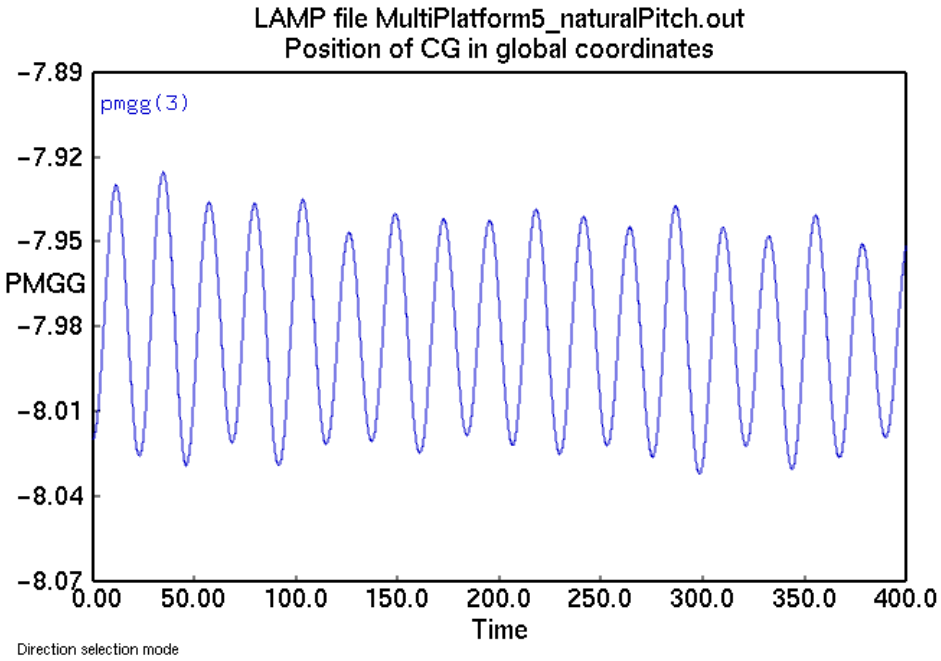
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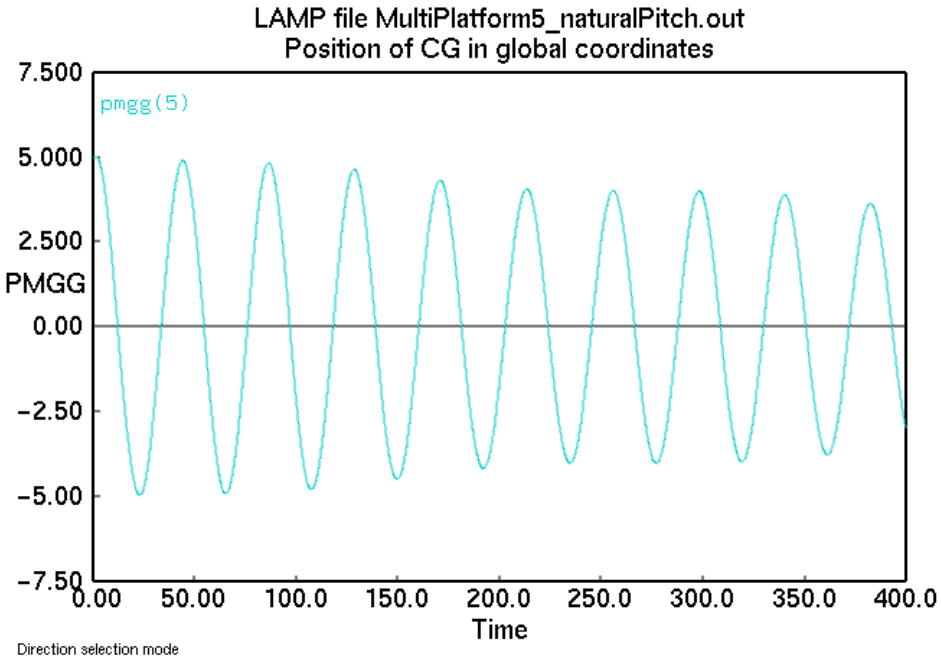
Relative Motions

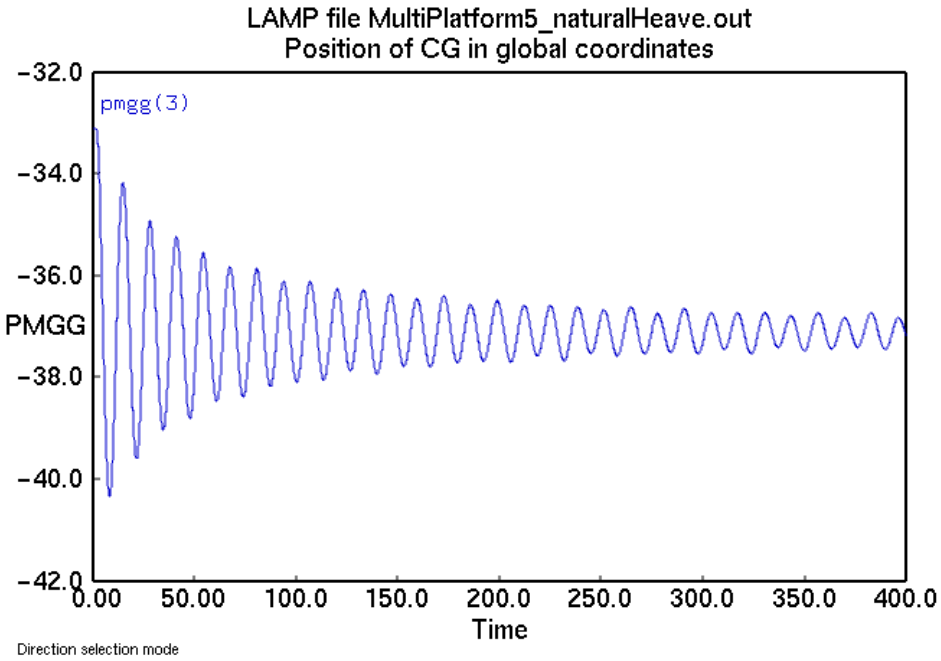
APPENDIX- Natural Periods


LAMP file MultiPlatform5_naturalHeave.out
Position of CG in global coordinates
pmgg(3)
-2.00
-4.00
-6.00
PMGG
-8.00
-10.0
-12.0
-14.0
0.00
50.00
100.0
150.0
200.0
250.0
300.0
350.0
400.0
Time
Direction selection mode


LAMP file MultiPlatform5_naturalPitch.out
Position of CG in global coordinates
pmgg(5)
7.500
5.000
2.500
PMGG
0.00
-2.50
-5.00
-7.50
0.00
50.00
100.0
150.0
200.0
250.0
300.0
350.0
400.0
Time
Direction selection mode


LAMP file MultiPlatform5_naturalPitch.out
Position of CG in global coordinates
pmgg(3)
-7.89
-7.92
-7.95
PMGG
-7.98
-8.01
-8.04
-8.07
0.00
50.00
100.0
150.0
200.0
250.0
300.0
350.0
400.0
Time
Direction selection mode


LAMP file MultiPlatform5_naturalPitch.out
Position of CG in global coordinates
pmgg(5)
7.500
5.000
2.500
PMGG
0.00
-2.50
-5.00
-7.50
0.00
50.00
100.0
150.0
200.0
250.0
300.0
350.0
400.0
Time
Direction selection mode



Platform

Roll Decay Coefficients for LAMP file MultiPlatform5_naturalRoll.out

Avg. Roll Angle	Roll Decay Coefficient	Roll Period
4.31512	0.101904	35.5281
3.13970	0.100284	35.4782
2.29006	0.100659	35.5298
1.66694	0.101688	35.5341
1.21216	0.101023	35.5150
0.884461	0.993700E-01	35.5342
0.647372	0.992766E-01	35.5821
0.472909	0.100884	35.6061
0.344212	0.101421	35.5873
0.250721	0.100130	35.5667
0.183211	0.994795E-01	35.5939
0.133834	0.100619	35.6251
0.973596E-01	0.102197	35.6097
0.706482E-01	0.101922	35.5730
0.513848E-01	0.100543	35.5637
0.374568E-01	0.100761	35.5858
0.272369E-01	0.102324	35.6028
0.197510E-01	0.102255	35.5561
0.143345E-01	0.101715	35.5424
0.104336E-01	0.100275	35.5641
0.759582E-02	0.102096	35.5913

Roll Period (avg)= 35.5652 in output time units.
Roll Freq (avg)= 0.176667 in output frequency units.

REMORA

Roll Decay Coefficients for LAMP file MultiPlatform5_naturalRoll.out

Avg. Roll Angle	Roll Decay Coefficient	Roll Period
4.31210	0.102434	39.4516
3.13727	0.996127E-01	39.0444
2.28244	0.103520	39.3426
1.65589	0.100257	39.0919
1.20278	0.103844	39.3632
0.872155	0.100200	39.1505
0.633892	0.103455	39.3845
0.460373	0.995434E-01	39.1923
0.335400	0.102557	39.3869
0.244294	0.986010E-01	39.2072
0.178511	0.101586	39.3638
0.130381	0.978518E-01	39.1989
0.954708E-01	0.101038	39.3224
0.698261E-01	0.975682E-01	39.1772
0.511641E-01	0.100920	39.2764
0.374167E-01	0.978095E-01	39.1648
0.273911E-01	0.101291	39.2289
0.200034E-01	0.983507E-01	39.1600
0.146230E-01	0.101615	39.2099

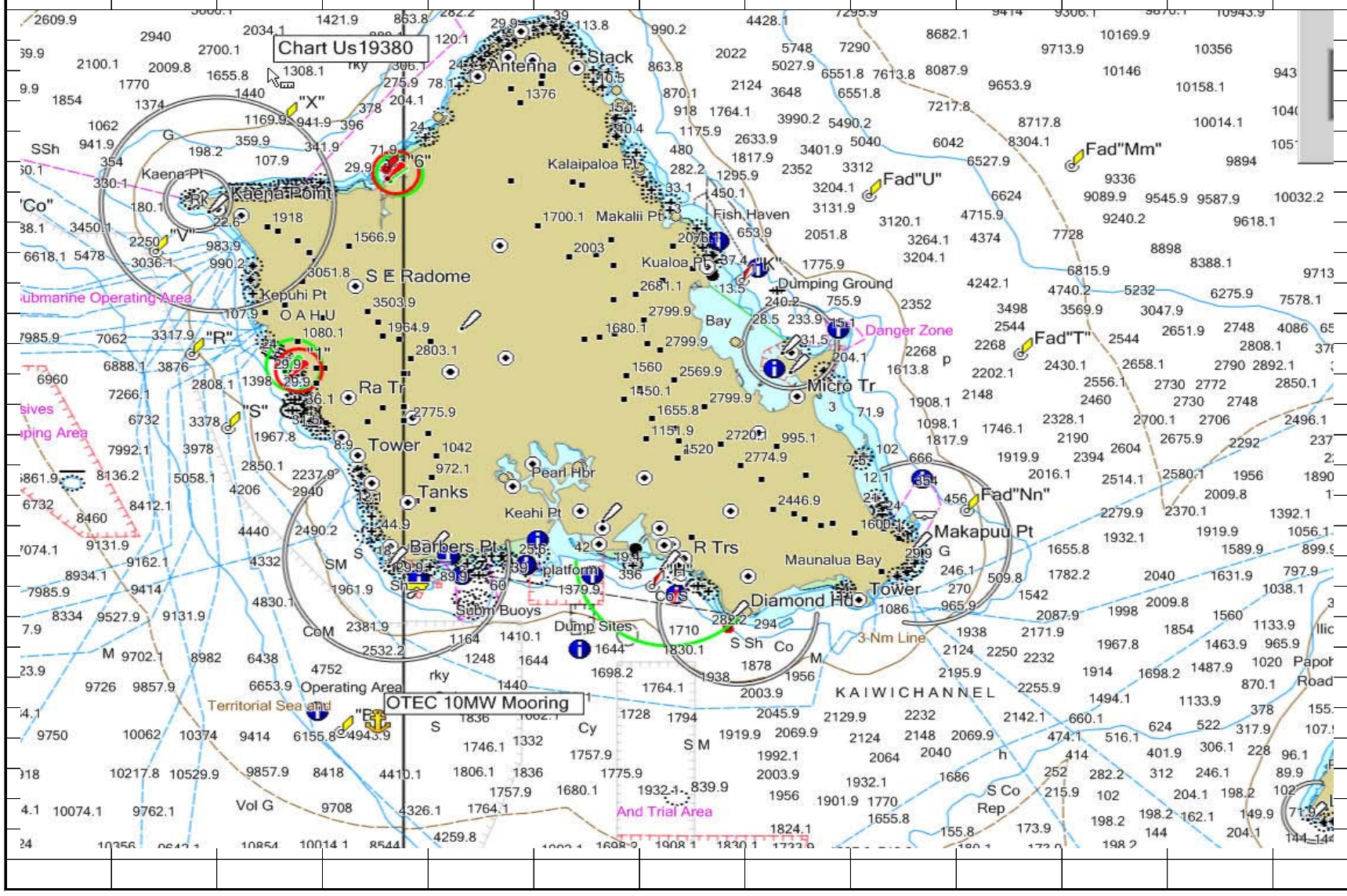
Roll Period (avg)= 39.2483 in output time units.
R

Remora Iteration 2.1

LAMP Set-Up

Assumptions and Conditions

Sea State Conditions								
SS	H 1/3	Tm	Source	Short Crested				
SS5sc	3.26	9.7	Nato	cos^2				
SS6sc	5	12.4	Nato	cos^2				
SS-4sc	1.88	8.8	Nato	cos^2				
SS-3sc	1.25	7.5	Nato-Max Ht, (normally .88m) Most Probable Modal Period					
SS-3 steve	1.4	6.5		PM spectra, wind based				
Swell	1.5	14						
Do-								
Rerun at new sea states and gyradii and fixed in surge								
damping panels on Platform								
LIST- PLATFORM & REMORA								
Orca Hydrostatics								
LAMP Hydrostatics								
LAMP Viscous Appendages								
Damping added same as OPT spar								
Weights and Inertias								
Reference- Holcomb								
Remora: email 07May2010								
Full Load Disp (w water) = 10025 mt								
LCG = 54.11 m from top of remora								
VCG = 7.484 m from platform side of remora								
TCG = 0.0 m								
kxx = 60.421 m								
kyy = 60.432 m								
kzz = 5.89 m								


Chart Us19380
OTEC 10MW Mooring
Kaena Point
Kaena Pt
Kepuhi Pt
S E Radome
O A H U
Ra Tr
Tower
Tanks
Barbers Pt
Pearl Hbr
Keahi Pt
Kalaipaloa Pt
Makalii Pt
Kualoa Pt
Fish Haven
Dumping Ground
Danger Zone
Micro Tr
Bay
R Trs
Maunalua Bay
Makapuu Pt
Diamond Hd
Tower
Subm Buoys
Dump Sites
3 Nm Line
K A I W I C H A N N E L
Territorial Sea and
Operating Area
And Trial Area
Vol G
Submarine Operating Area
Antenna
Stack
"X"
"V"
"R"
"S"
"6"
"K"
Fad"U"
Fad"T"
Fad"Mm"
Fad"Nn"
Co"
"B"

	21.19139	158.176								

4.2. Offshore Sites

The selected site for the pilot plant is shown in Figure 5.
Parameters for this site are:

- Coordinates: Lat: 21 deg 10' 8.9" N Long: 158 deg 7' 21.36" W
- Water depth 1100 m

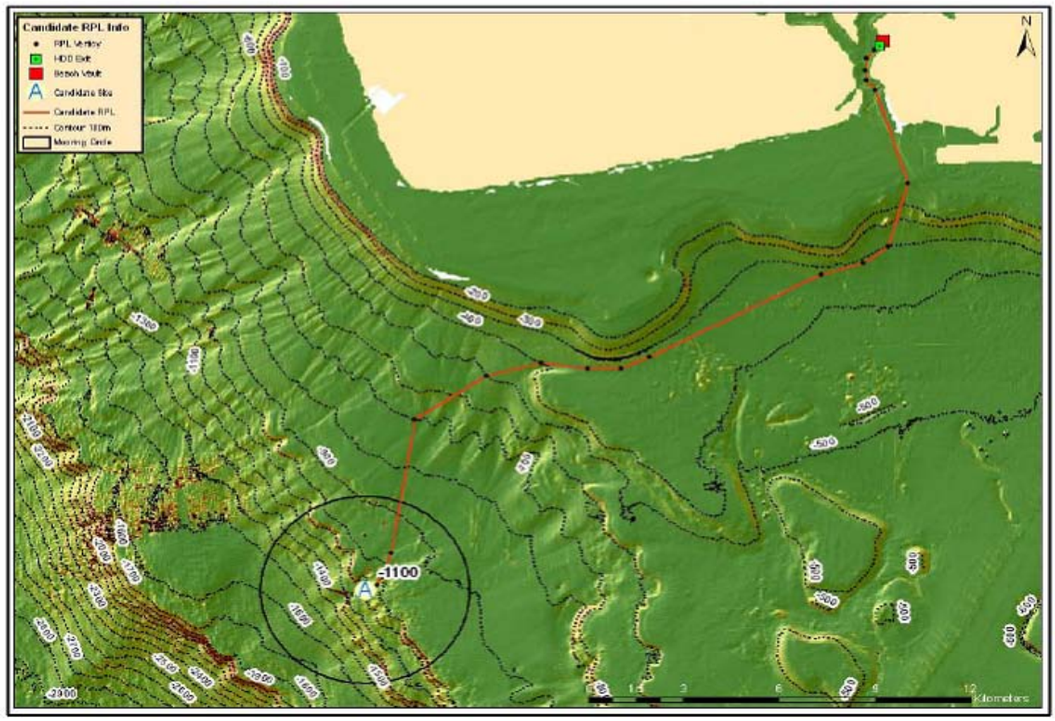


Figure 5 Proposed Pilot Plant Site [2]

Platform&Remora: email 12May2009								
Platform: email 19May2010								
Platform Only								

Table 9.3: Weight Case#103: Fabrication Condition With CWP Manufacturing Eqpts.

Description	Weight (mts)	Load (mts)		XCG (EW) (m)	YCG (NS) (m)	ZCG (UP) (m)	Kxx (NS) (m)	Kyy (EW) (m)	Kzz (UP) (m)	FSC (mts-m)	Capacity (mts)
1 Topsides Equipments	1989	-	-	0.76	0.00	44.43					
2 Topsides Structure	2164	-	-	0.33	0.33	40.12					
3 Hull (Structure and Outfittings)	6481	-	-	0.00	0.00	13.49					
3 Hull Storage (w/ dead oil)	0	-	-	0.00	0.00	10.62					
4 Entrapped Water in Diffuser	261	-	-	0.00	0.00	5.00					
5 Remora - A	0	-	-	-25.00	0.00	14.30					
6 Remora - B	0	-	-	25.00	0.00	14.30					
Weight Sub-total	10,895			0.20	0.07	24.23					
5 Mooring Loads	-	403		0.00	0.00	3.00	-	-	-	-	-
6 Cold Water Pipe Loads	-	352		0.00	0.00	1.50	-	-	-	-	-
Load Sub-total		755		0.00	0.00	2.30					
Weight & Force Sub-Total	11,650										
Ballast Tanks: Type		Load (%)	Sounding (m)				L	B	H		
North East Tanks											
NE Tank Variable Ballast Tank	237	47.3%	2.37	20.30	20.30	1.18	10.0	10.0	5.0	56	501
South East Tanks											
SE Tank Variable Ballast Tank	200	40.0%	2.00	20.30	-20.30	1.00	10.0	10.0	5.0	64	501
South West Tanks											
SW Tank Variable Ballast Tank	311	62.0%	3.10	-20.30	-20.30	1.55	10.0	10.0	5.0	40	501
North West Tanks											
NW Tank Variable Ballast Tank	241	48.0%	2.40	-20.30	20.30	1.20	10.0	10.0	5.0	55	501
Permanently Flooded Tanks											
13S1	646	100.0%	5.00	11.30	25.00	2.50	11.3	11.3	5.0	0	646
20S1	646	100.0%	5.00	25.00	11.30	2.50	11.3	11.3	5.0	0	646
40S1	646	100.0%	5.00	25.00	-11.30	2.50	11.3	11.3	5.0	0	646
53S1	646	100.0%	5.00	11.30	-25.00	2.50	11.3	11.3	5.0	0	646
53P1	646	100.0%	5.00	-11.30	-25.00	2.50	11.3	11.3	5.0	0	646
40P1	646	100.0%	5.00	-25.00	-11.30	2.50	11.3	11.3	5.0	0	646
20P1	646	100.0%	5.00	-25.00	11.30	2.50	11.3	11.3	5.0	0	646
13P1	646	100.0%	5.00	-11.30	25.00	2.50	11.3	11.3	5.0	0	646
30S1	456	100.0%	5.00	25.00	0.00	2.50	9.6	9.5	5.0	0	456
50C1	456	100.0%	5.00	0.00	-25.00	2.50	9.5	9.6	5.0	0	456
30P1	456	100.0%	5.00	-25.00	0.00	2.50	9.6	9.5	5.0	0	456
10C1	456	100.0%	5.00	0.00	25.00	2.50	9.5	9.6	5.0	0	456
Total Variable Ballast	7,984			-0.29	-0.09	2.35	23.2	23.2	27.4	215E+0	9E+3
(Trim+Reserve) ballast	7,984			-0.29	-0.09	2.35					
Residul ballast	0			0.00	0.00	0.00					
Total Mass	18,879			0.00	0.00	14.97					

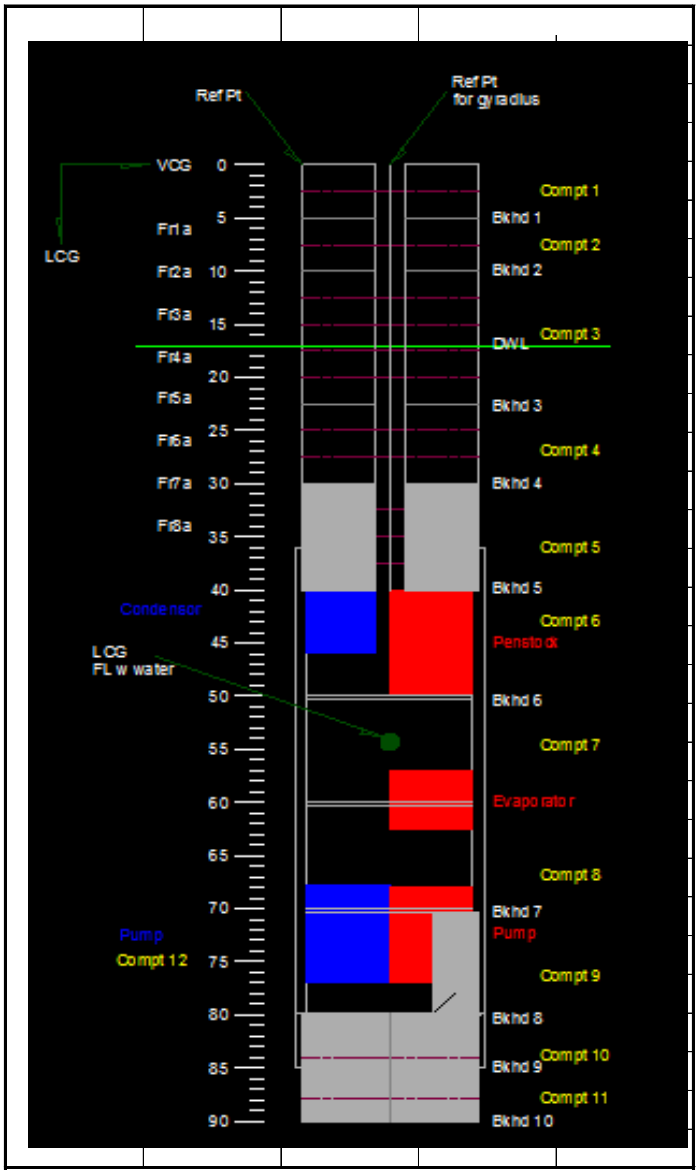
Displacement	=	19635 mts	FS_corr	=	0.01 m		KMT	= 19.4 m
Total liquid	=	7984 mts	KB	=	6.70 m		KML	= 19.4 m
Draft@gauge	=	23.00 m	KG	=	14.97 m		GMT (NS)	= 4.43 m
			KG_corr	=	14.98 m		GML (EW)	= 4.43 m
xcg: load+wt	(including	= 0.00 m	Heel (NS)	=	-0.02 degs		GMT_corr(NS	= 4.42 m
ycg: load+wt	moorings &	= 0.00 m	Trim (EW	=	-0.06 degs		GML_corr(EW	= 4.42 m
zcg: load+wt	cwp)	= 14.49 m	LCF	=	0.0 m		(NS)	= 26.6 m
			LCB	=	0.0 m		Kyy-Pitch (EW)	= 26.6 m
Total Mass Incl. CWP		= 19,231 mts	GMT (NS)	=	4.91 m	(w/	Kzz-Yaw (UP)	= 28.6 m
xcg: load+wt	(excluding	= 0.00 m	GML (EW	=	4.91 m	mooring	(XCG toward platform east - positive)	
ycg: load+wt	moorings &	= 0.00 m	GMT_corr	=	4.90 m	& cwp)	(YCG toward platform north - positive)	
zcg: load+wt	incl. cwp)	= 14.73 m	GML_corr	=	4.90 m		(ZCG up from base line)	

Platform	Gyradii,m	Gyr.^2,m^2
Kxx	26.6	
Kyy	26.6	707.56
Kzz	28.6	817.96

Table 9.4: Weight Case#104: Pilot Testing Condition, One Remora and One Power Unit Installed

Description	Weight (mts)	Load (mts)		XCG (EW) (m)	YCG (NS) (m)	ZCG (UP) (m)	Kxx (NS) (m)	Kyy (EW) (m)	Kzz (UP) (m)	FSC (mts-m)	Capacity (mts)
1 Topsides Equipments	1422	-	-	3.96	0.84	42.67				-	-
2 Topsides Structure	2164	-	-	0.34	0.34	40.16					
3 Hull (Structure and Outfittings)	6481	-	-	0.00	0.00	13.49					
3 Hull Storage (w/ dead oil)	0	-	-	0.00	0.00	10.62					
4 Entrapped Water in Diffuser	261	-	-	0.00	0.00	5.00					
5 Remora - A	5318	-	-	-25.00	0.00	-14.87					
6 Remora - B	0	-	-	25.00	0.00	-14.87					
Weight Sub-total	15,645			-8.09	0.12	10.05					
5 Mooring Loads	-	403		0.00	0.00	3.00	-	-	-	-	-
6 Cold Water Pipe Loads	-	352		0.00	0.00	1.50	-	-	-	-	-
Load Sub-total		755		0.00	0.00	2.30					
Weight & Force Sub-Total	16,400										
Ballast Tanks: Type		Load (%)	Sounding (m)				L	B	H		
North East Tanks											
NE Tank Variable Ballast Tank	389	77.6%	3.88	20.30	20.30	1.94	10.0	10.0	5.0	24	501
South East Tanks											
SE Tank Variable Ballast Tank	389	77.6%	3.88	20.30	-20.30	1.94	10.0	10.0	5.0	24	501
South West Tanks											
SW Tank Variable Ballast Tank	389	77.6%	3.88	-20.30	-20.30	1.94	10.0	10.0	5.0	24	501
North West Tanks											
NW Tank Variable Ballast Tank	389	77.6%	3.88	-20.30	20.30	1.94	10.0	10.0	5.0	24	501
Permanently Flooded Tanks											
13S1	646	100.0%	5.00	11.30	25.00	2.50	11.3	11.3	5.0	0	646
20S1	646	100.0%	5.00	25.00	11.30	2.50	11.3	11.3	5.0	0	646
40S1	646	100.0%	5.00	25.00	-11.30	2.50	11.3	11.3	5.0	0	646
53S1	646	100.0%	5.00	11.30	-25.00	2.50	11.3	11.3	5.0	0	646
53P1	646	100.0%	5.00	-11.30	-25.00	2.50	11.3	11.3	5.0	0	646
40P1	646	100.0%	5.00	-25.00	-11.30	2.50	11.3	11.3	5.0	0	646
20P1	646	100.0%	5.00	-25.00	11.30	2.50	11.3	11.3	5.0	0	646
13P1	646	100.0%	5.00	-11.30	25.00	2.50	11.3	11.3	5.0	0	646
30S1	456	100.0%	5.00	25.00	0.00	2.50	9.6	9.5	5.0	0	456
50C1	456	100.0%	5.00	0.00	-25.00	2.50	9.5	9.6	5.0	0	456
30P1	456	100.0%	5.00	-25.00	0.00	2.50	9.6	9.5	5.0	0	456
10C1	456	100.0%	5.00	0.00	25.00	2.50	9.5	9.6	5.0	0	456
Total Variable Ballast	8,551			0.00	0.00	2.40	20.1	20.8	28.0	95E+0	9E+3
(Trim+Reserve) ballast	8,551			0.00	0.00	2.40					
Residul ballast	0			0.00	0.00	0.00					
Total Mass	24,196			-5.23	0.08	7.35					

Displacement	=	24952 mts	FS_corr	=	0.01 m		KMT	=	28.4 m
Total liquid	=	8551 mts	KB	=	4.90 m		KML	=	15.0 m
Draft@gauge	=	23.00 m	KG	=	7.35 m		GMT (NS)	=	21.05 m
			KG_corr	=	7.35 m		GML (EW)	=	7.65 m
xcg: load+wt	(including	= -5.07 m	Heel (NS)	=	degs		GMT_corr(NS)	=	21.05 m
ycg: load+wt	moorings &=	0.08 m	Trim (EW	=	degs		GML_corr(EW)	=	7.65 m
zcg: load+wt	cwp) =	7.19 m	LCF	=	m		Kxx-Roll (NS)	=	31.2 m
			LCB	=	m		Kyy-Pitch (EW)	=	36.1 m
Total Mass Incl. CWP	=	24,548 mt	GMT (NS)	=	21.21 m		Kzz-Yaw (UP)	=	31.1 m
xcg: load+wt	(excluding =	-5.16 m	GML (EW	=	7.81 m	(w/ mooring & cwp)	(XCG toward platform east - positive)		
ycg: load+wt	moorings &=	0.08 m	GMT_corr	=	21.20 m		(YCG toward platform north - positive)		
zcg: load+wt	incl. cwp) =	7.26 m	GML_corr	=	7.80 m		(ZCG up from base line)		


Ref Pt
Ref Pt
for gyradius
VCG
LCG
Fr1a
Fr2a
Fr3a
Fr4a
Fr5a
Fr6a
Fr7a
Fr8a
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
DWL
Compt 1
Bkhd 1
Compt 2
Bkhd 2
Compt 3
Bkhd 3
Compt 4
Bkhd 4
Compt 5
Bkhd 5
Compt 6
Penstock
Bkhd 6
Compt 7
Evaporator
Compt 8
Bkhd 7
Pump
Compt 9
Bkhd 8
Compt 10
Bkhd 9
Compt 11
Bkhd 10
Condensor
LCG
FL w water
Pump
Compt 12

Lamp Mass Properties

(Note that there are some slight Displacement differences from the original Surface models due to loss of resolution in Mesh model.

Ship 1 of 2- OTEC PLATFORM
Computed Hydrostatic Values:
Wetted Surface Area ..... S = 11883.
Submerged Volume ..... V = 18161.
Longitudinal Center of Buoyancy ... LCB = 0.57591E-05
Transverse Center of Buoyancy ..... TCB = 0.13052E-06
Vertical Center of Buoyancy ..... VCB = -16.300
Displacement (mass) ..... M = 18632.
Displacement (weight) ..... W = 0.18271E+06
Waterplane Area ..... Awp = 370.39
Longitudinal Center of Flotation .. LCF = 0.43633E-05
Longitudinal Metacentric Height ... BML = 13.000
Transverse Center of Flotation .... TCF = -0.39139E-05
Transverse Metacentric Height ..... BMT = 13.000
Vertical Center of Gravity (input) . VCG = -8.0200
Longitudinal Metacentric Height ... GML = 4.7192
Transverse Metacentric Height ..... GMT = 4.7192
Waterline Length ..... LWL = 62.000
Waterline Maximum Beam ..... BWL = 62.000
Maximum Draft ..... T = 23.000
Overall Length ..... LOA = 65.603
Maximum Beam ..... B = 65.603

Adjusting ship mass and mass center to match hydrostatics:
Input value of SMA = 1.00000
Corrected value of SMA = 18631.6
Input value of RGRAV0 = 0.00000 0.00000 -8.02000

Ship 2 of 2- OTEC REMORA
Computed Hydrostatic Values:
Wetted Surface Area ..... S = 2142.7
Submerged Volume ..... V = 5227.8
Longitudinal Center of Buoyancy ... LCB = -39.000
Transverse Center of Buoyancy ..... TCB = 0.35656E-06
Vertical Center of Buoyancy ..... VCB = -26.651
Displacement (mass) ..... M = 5363.2
Displacement (weight) ..... W = 52596.
Waterplane Area ..... Awp = 167.40
Longitudinal Center of Flotation .. LCF = -39.000
Longitudinal Metacentric Height ... BML = 0.45102
Transverse Center of Flotation .... TCF = -0.22012E-07
Transverse Metacentric Height ..... BMT = 0.45102
Vertical Center of Gravity (input) . VCG = -37.110
Longitudinal Metacentric Height ... GML = 10.910
Transverse Metacentric Height ..... GMT = 10.910
Waterline Length ..... LWL = 15.000
Waterline Maximum Beam ..... BWL = 15.000
Maximum Draft ..... T = 73.000
Overall Length ..... LOA = 15.000
Maximum Beam ..... B = 15.000

Adjusting ship mass and mass center to match hydrostatics:
Input value of SMA = 1.00000
Corrected value of SMA = 5363.24
Input value of RGRAV0 = -39.0000 0.00000 -37.1100

LAMP SETUP FOR ADDING A SECONDARY DUAL WAVE SPECTRUM

```
$ADDSEA:
!2nd (additional) seaway definition:
! Long-crested swell defined by single mode Ochi spectrum with narrow peak
!ADDSEA01 ISEA - Seaway option
            7
!ADDSEA01 (cont) SIGWHT1 TMODAL1 SHAPE1 SIGWHT2 TMODAL2 SHAPE2 (Ochi Spectrum)
              3.0    20.00   6.0     0.0     0.0    0.0
!ADDSEA01 (cont) SEAHD  SPREAD  NFREQ  NHEAD  IWVRLZ
              90.    0.0     41     1      2
```

Natural Period Check

Undamped Natural Period Calc		Platform	Platform	Remora	Remora
Volume	V	18593.2	18593.2	5467.847	5468.847
Waterplane Area	Awp	380	380	177	177
Added Mass Coef	A'33	0.5	1	0.5	1
Added Mass Coef	A'55	0.5	1	0.5	1
GML = GMT	GML	4.78	4.78	11	11
Length or beam	L	60	60	15	15
Gyradii, m	Kp	26.6	26.6	60.4	60.4
Gyradii, % of L	Kp'	0.44	0.44	4.03	4.03
Heave Period, s	**T_z**	*17.2*	*19.8*	*13.7*	*15.8*
Roll&Pitch Per. ,s	**T_roll&pitch**	*45.9*	*60.2*	*37.1*	*37.6*

See Natural Period runs of system with 4m heave offset or 5 degree pitch and roll.

Remora Iteration 2.1

LAMP Statistics—Round 1

OTEC PLATFORM AND REMORA

Project Notes and Run Setup

Round 1	Assumptions- free to surge but fixed in sway and yaw.
Multiplatform4	Ten Minute runs at 0.1sec time step. One check run at .05 showed little differnce in the stats
Remora4	Observation- movement up wave by both the platform and the remora. See paper by Weems
	Platform-Truncated Columns, had no viscous appendages or added damping
	Remora had only upper and lower cylinders included (no lattice structure)
Round 2	Assumptions- fixed in surge, sway and yaw.
	Added "bilge keels" to the base of the Platform for added viscous damping, otherwise untethered.

OTEC PLATFORM AND REMORA LAMP SEAKEEPING STATS

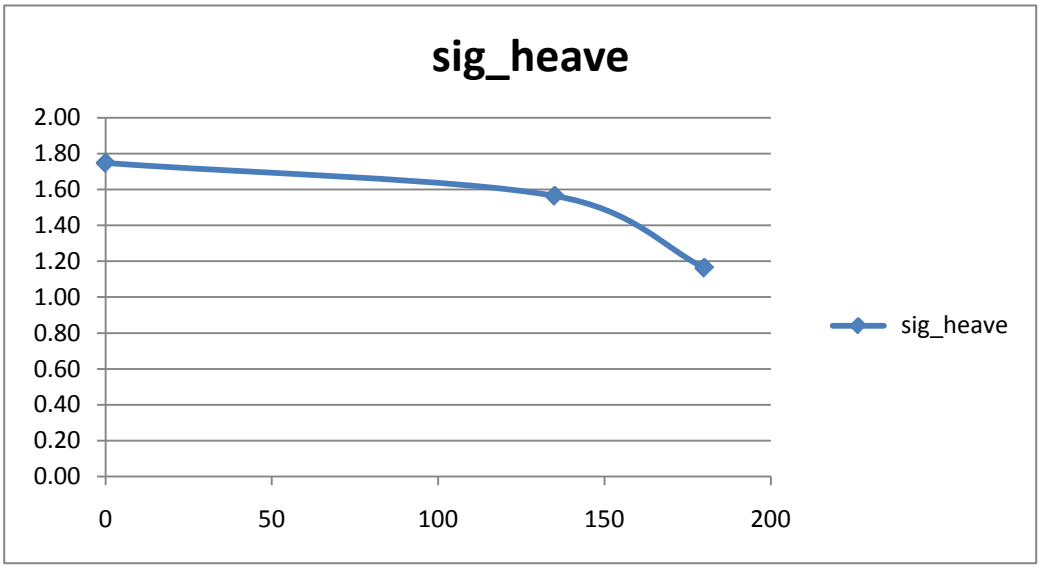
Table of motion and load stats for two-body cases

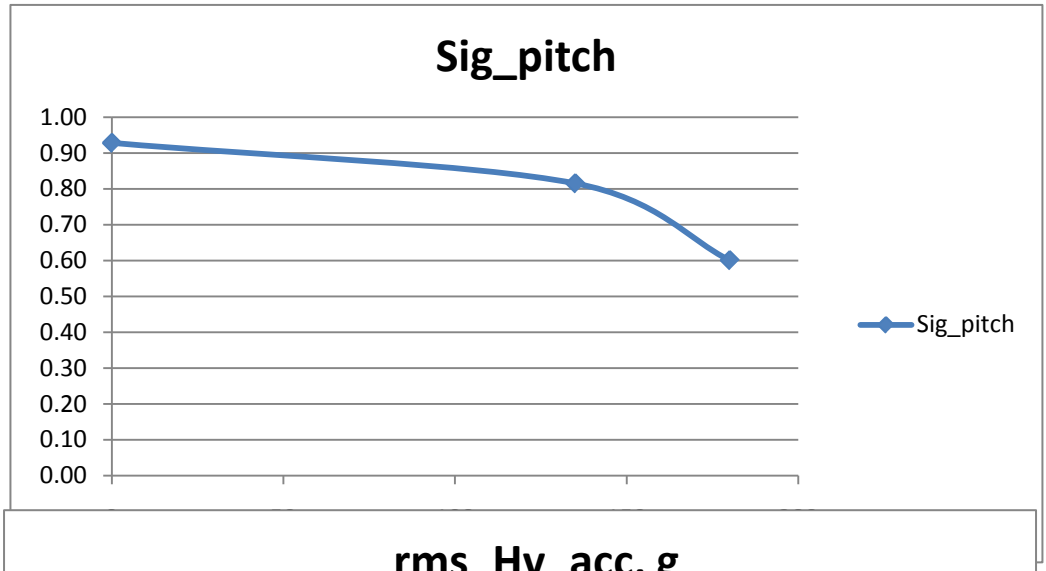
Case	File	Sea State	Heading	Avg_heave	Avg_pitch	rms_heave	rms_roll	rms_pitch	ıs_Heave_a	ms_Hv_acc,	sig_heave	Sig_pitch
Case 1- Platform	ss5sc_0kt_000	5sc	0	-11.96	0.00	0.24	0.15	0.32	0.05	0.0055	0.46	0.67
Case 2- Platform	ss5sc_0kt_135	5sc	135	-11.96	0.01	0.24	0.22	0.30	0.06	0.0056	0.47	0.61
Case 3- Platform	ss5sc_0kt_180	5sc	180	-11.96	0.00	0.24	0.15	0.32	0.06	0.0056	0.47	0.68
Case 4- Platform	ss6sc_0kt_000	6sc	0	-11.94	0.00	0.51	0.25	0.48	0.11	0.0109	1.05	0.98
Case 5- Platform	ss6sc_0kt_135	6sc	135	-11.93	0.01	0.58	0.38	0.47	0.12	0.0118	1.21	0.92
Case 6- Platform	ss6sc_0kt_180	6sc	180	-11.94	-0.01	0.53	0.25	0.50	0.11	0.0113	1.11	1.01
Case	File	Sea State	Heading	Avg_heave	Avg_pitch	rms_heave	rms_roll	rms_pitch	ıs_Heave_a	ms_Hv_acc,	sig_heave	Sig_pitch
Case 1- Remora	ss5sc_0kt_000	5sc	0	-37.12	0.02	0.87	0.14	0.48	0.24	0.0244	1.75	0.93
Case 2- Remora	ss5sc_0kt_135	5sc	135	-37.11	0.00	0.79	0.19	0.43	0.22	0.0226	1.56	0.82
Case 3- Remora	ss5sc_0kt_180	5sc	180	-37.11	0.02	0.59	0.18	0.31	0.17	0.0169	1.16	0.60
Case 4- Remora	ss6sc_0kt_000	6sc	0	-37.09	0.09	2.10	0.31	1.18	0.50	0.0512	4.18	2.38
Case 5- Remora	ss6sc_0kt_135	6sc	135	-37.08	-0.25	2.39	0.54	1.58	0.57	0.0582	4.67	3.03
Case 6- Remora	ss6sc_0kt_180	6sc	180	-37.08	-0.17	1.86	0.30	0.80	0.45	0.0456	3.65	1.45

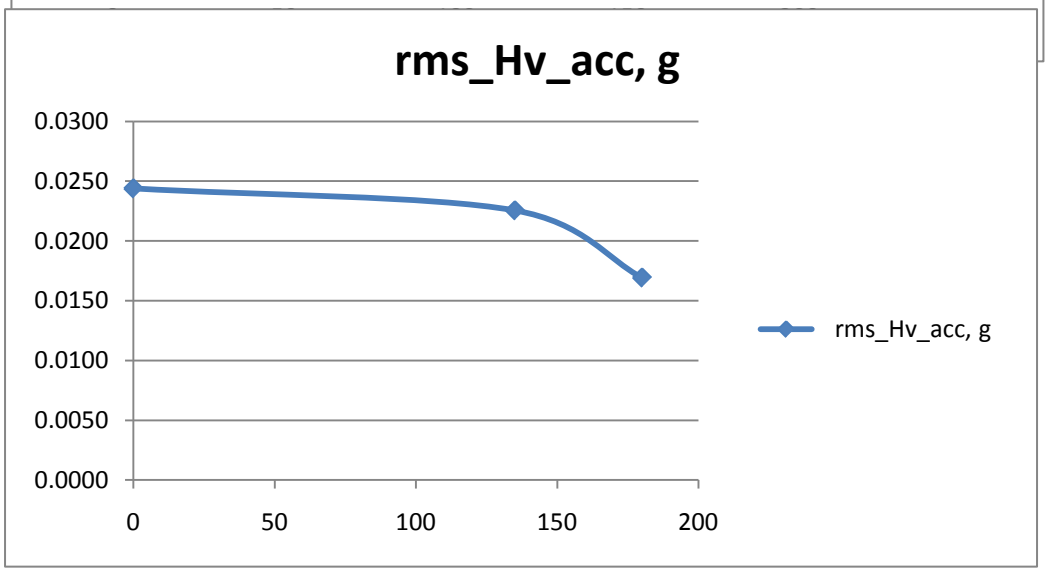
Table of motion and load stats for two-body cases

Case	File	Sea State	Heading	Avg_heave	Avg_pitch	rms_heave	rms_roll	rms_pitch	ıs_Heave_a	ms_Hv_acc,	sig_heave	Sig_pitch
Case 1- Platform	ss5sc_0kt_000		0	-11.964	0.001	0.238	0.152	0.323	0.054	0.006	0.464	0.670
Case 1- Remora	ss5sc_0kt_000		0	-37.118	0.016	0.866	0.137	0.480	0.239	0.024	1.748	0.928
Case 2- Platform	ss5sc_0kt_135		135	-11.960	0.008	0.239	0.221	0.304	0.055	0.006	0.468	0.606
Case 2- Remora	ss5sc_0kt_135		135	-37.115	0.001	0.790	0.193	0.430	0.221	0.023	1.564	0.815
Case 3- Platform	ss5sc_0kt_180		180	-11.964	-0.002	0.242	0.154	0.324	0.055	0.006	0.471	0.682
Case 3- Remora	ss5sc_0kt_180		180	-37.115	0.015	0.591	0.182	0.307	0.166	0.017	1.163	0.601
Case 4- Platform	ss6sc_0kt_000		0	-11.939	0.004	0.513	0.248	0.484	0.107	0.011	1.049	0.981
Case 4- Remora	ss6sc_0kt_000		0	-37.092	0.088	2.096	0.309	1.178	0.502	0.051	4.181	2.378
Case 5- Platform	ss6sc_0kt_135		135	-11.929	0.011	0.582	0.382	0.466	0.116	0.012	1.211	0.916
Case 5- Remora	ss6sc_0kt_135		135	-37.077	-0.253	2.385	0.542	1.579	0.571	0.058	4.668	3.028
Case 6- Platform	ss6sc_0kt_180		180	-11.941	-0.009	0.528	0.249	0.504	0.111	0.011	1.107	1.007
Case 6- Remora	ss6sc_0kt_180		180	-37.085	-0.169	1.862	0.302	0.801	0.447	0.046	3.653	1.449

Notes: free to surge. Motion of Remora traveled through the Platform.


sig_heave
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
50
100
150
200
sig_heave


Sig_pitch
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Sig_pitch


rms_Hv_acc, g
0.0300
0.0250
0.0200
0.0150
0.0100
0.0050
0.0000
0
50
100
150
200
rms_Hv_acc, g

Remora Iteration 2.1

LAMP Statistics—Round 2

Case	File	Sea State	Heading	Avg_heave	Avg_pitch	rms_heave	rms_roll	rms_pitch	ıs_Heave_a	ms_Hv_acc,	sig_heave	Sig_pitch	Comments
Case 0- Platform	ss5sc_0kt_000TS05	5sc	0	-11.96	0.00	0.22	0.15	0.32	0.05	0.0054	0.43	0.67	Finer Time Step (t=.05s)
Case 0- Remora	ss5sc_0kt_000TS05	5sc	0	-37.12	0.01	0.85	0.14	0.46	0.23	0.0239	1.73	0.88	
Case 1- Platform	ss5sc_0kt_000	5sc	0	-11.96	0.00	0.24	0.15	0.32	0.05	0.0055	0.46	0.67	
Case 1- Remora	ss5sc_0kt_000	5sc	0	-37.12	0.02	0.87	0.14	0.48	0.24	0.0244	1.75	0.93	
Case 2- Platform	ss5sc_0kt_045	5sc	45	-11.96	0.01	0.23	0.23	0.22	0.05	0.0055	0.46	0.46	
Case 2- Remora	ss5sc_0kt_045	5sc	45	-37.11	-0.01	0.90	0.23	0.64	0.25	0.0254	1.66	1.20	
Case 3- Platform	ss5sc_0kt_135	5sc	135	-11.96	0.01	0.24	0.22	0.30	0.06	0.0056	0.47	0.61	
Case 3- Remora	ss5sc_0kt_135	5sc	135	-37.11	0.00	0.79	0.19	0.43	0.22	0.0226	1.56	0.82	
Case 4- Platform	ss5sc_0kt_180	5sc	180	-11.96	0.00	0.24	0.15	0.32	0.06	0.0056	0.47	0.68	
Case 4- Remora	ss5sc_0kt_180	5sc	180	-37.11	0.02	0.59	0.18	0.31	0.17	0.0169	1.16	0.60	
Case 5- Platform	ss6sc_0kt_000	6sc	0	-11.94	0.00	0.51	0.25	0.48	0.11	0.0109	1.05	0.98	
Case 5- Remora	ss6sc_0kt_000	6sc	0	-37.09	0.09	2.10	0.31	1.18	0.50	0.0512	4.18	2.38	
Case 6- Platform	ss6sc_0kt_045	6sc	45	-11.93	0.03	0.60	0.38	0.43	0.11	0.0111	1.24	0.86	
Case 6- Remora	ss6sc_0kt_045	6sc	45	-37.06	0.04	2.45	0.68	1.22	0.57	0.0586	4.83	2.44	
Case 7- Platform	ss6sc_0kt_135	6sc	135	-11.93	0.01	0.58	0.38	0.47	0.12	0.0118	1.21	0.92	
Case 7- Remora	ss6sc_0kt_135	6sc	135	-37.08	-0.25	2.39	0.54	1.58	0.57	0.0582	4.67	3.03	
Case 8- Platform	ss6sc_0kt_180	6sc	180	-11.94	-0.01	0.53	0.25	0.50	0.11	0.0113	1.11	1.01	
Case 8- Remora	ss6sc_0kt_180	6sc	180	-37.08	-0.17	1.86	0.30	0.80	0.45	0.0456	3.65	1.45	

OTEC PLATFORM AND REMORA LAMP SEAKEEPING STATS

Platform and Remora fixed in Surge, Sway, Yaw. Added Viscous Appendages to Platform, Updated CG's and Inertia's.

Table of motion and load stats for two-body cases

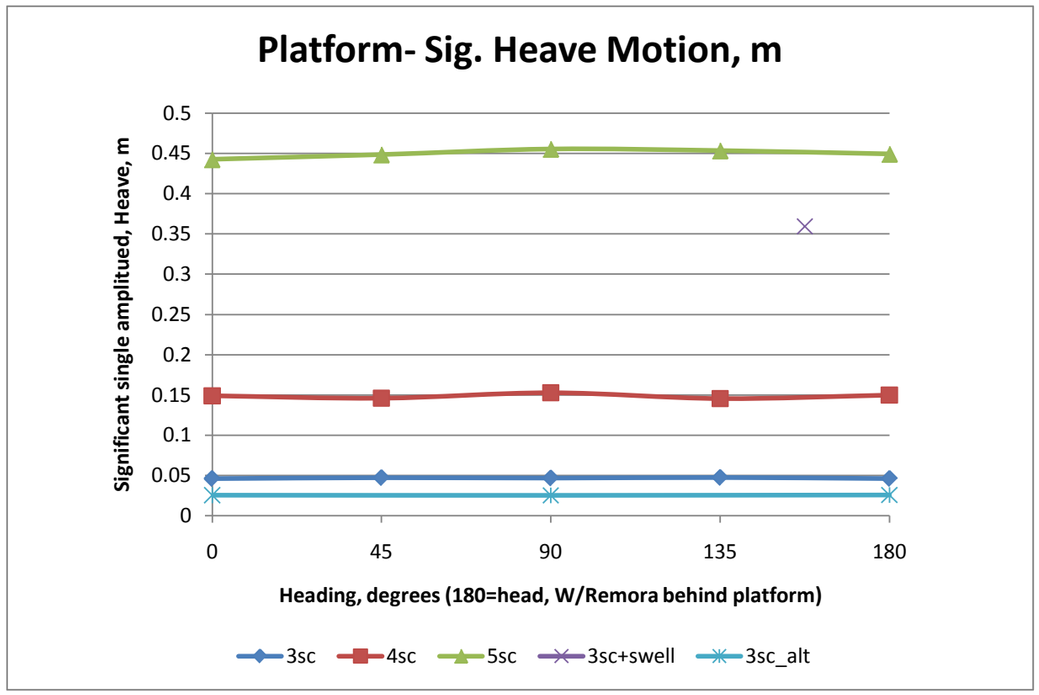
Case	File*	Sea State	Heading	Avg_heave	Avg_roll	Avg_pitch	rms_heave	rms_roll	rms_pitch	acc in mpss rms_Heave_ac	acc in g's rms_Heave_	sig_heave	Sig_roll	Sig_pitch
Case 1- Platform	ss3sc_0kt_000	3sc	0	-8.00753	7.45E-03	-8.26E-05	2.38E-02	4.14E-02	7.61E-02	1.14E-02	0.0012	4.62E-02	8.22E-02	0.159374
Case 2- Platform	ss3sc_0kt_045	3sc	45	-8.00752	4.41E-03	6.00E-03	2.42E-02	5.64E-02	6.21E-02	1.13E-02	0.0012	4.73E-02	0.116938	0.124128
Case 3- Platform	ss3sc_0kt_090	3sc	90	-8.00746	-5.38E-04	8.79E-03	2.41E-02	7.06E-02	5.83E-02	1.14E-02	0.0012	4.69E-02	0.151939	0.107781
Case 4- Platform	ss3sc_0kt_135	3sc	135	-8.00753	-5.90E-03	5.61E-03	2.43E-02	5.86E-02	6.57E-02	1.14E-02	0.0012	4.76E-02	1.18E-01	0.133796
Case 5- Platform	ss3sc_0kt_180	3sc	180	-8.00751	-7.54E-03	2.79E-04	2.38E-02	4.15E-02	7.79E-02	1.14E-02	0.0012	4.63E-02	8.24E-02	0.165257
Case 6- Platform	ss4sc_0kt_000	4sc	0	-8.00255	1.49E-02	-7.75E-04	7.21E-02	9.86E-02	0.324231	2.71E-02	0.0028	0.149086	0.186174	0.638612
Case 7- Platform	ss4sc_0kt_045	4sc	45	-8.00255	8.13E-03	1.37E-02	7.15E-02	0.130933	0.316597	2.73E-02	0.0028	0.146032	0.267009	0.624306
Case 8- Platform	ss4sc_0kt_090	4sc	90	-8.0024	-1.78E-03	2.20E-02	7.38E-02	0.158565	0.302448	2.76E-02	0.0028	0.152833	0.329406	0.539251
Case 9- Platform	***ss4sc_0kt_135***	***4sc***	***135***	-8.00256	-1.20E-02	1.41E-02	7.11E-02	1.34E-01	0.314466	2.74E-02	0.0028	0.145543	0.260962	0.607957
Case 10- Platform	ss4sc_0kt_180	4sc	180	-8.00249	-1.52E-02	8.99E-04	7.23E-02	9.91E-02	0.326968	2.71E-02	0.0028	0.149896	0.186705	0.643332
Case 11- Platform	ss5sc_0kt_000	5sc	0	-7.98505	3.66E-02	7.80E-03	0.222957	0.221319	0.504718	5.61E-02	0.0057	0.442538	0.408646	0.922868
Case 12- Platform	ss5sc_0kt_045	5sc	45	-7.98493	1.75E-02	3.41E-02	0.224679	0.297708	0.413414	5.65E-02	0.0058	0.448488	0.5933	0.807966
Case 13- Platform	ss5sc_0kt_090	5sc	90	-7.98509	-6.98E-03	3.61E-02	0.228927	0.337757	0.306442	5.77E-02	0.0059	0.455502	0.68636	0.602211
Case 14- Platform	ss5sc_0kt_135	5sc	135	-7.98487	-3.43E-02	1.89E-02	0.227651	0.278857	0.449898	5.71E-02	0.0058	0.453491	0.551748	0.871198
Case 15- Platform	ss5sc_0kt_180	5sc	180	-7.98492	-3.63E-02	-7.10E-03	0.226507	0.22126	0.506401	5.65E-02	0.0058	0.449304	0.408969	0.903115
Case 16- Platform	ss3sc_swell__0kt_18(	3sc+swell	157.5	-8.00645	-6.97E-03	-4.33E-04	1.82E-01	1.38E-01	1.59E-01	3.89E-02	0.0040	3.59E-01	2.71E-01	0.318008
Case 17- Platform	ss3sc-ss_0kt_000	3sc_alt	0	-8.00731	7.28E-03	3.18E-06	1.33E-02	3.22E-02	6.81E-02	7.74E-03	0.0008	2.55E-02	6.21E-02	1.34E-01
Case 18- Platform	ss3sc-ss_0kt_090	3sc_alt	90	-8.00727	-2.77E-04	8.30E-03	1.33E-02	4.84E-02	5.07E-02	7.46E-03	0.0008	2.54E-02	9.97E-02	9.38E-02
Case 19- Platform	ss3sc-ss_0kt_180	3sc_alt	180	-8.00731	-7.39E-03	1.71E-04	1.34E-02	3.20E-02	6.68E-02	7.67E-03	0.0008	2.57E-02	6.11E-02	0.134382

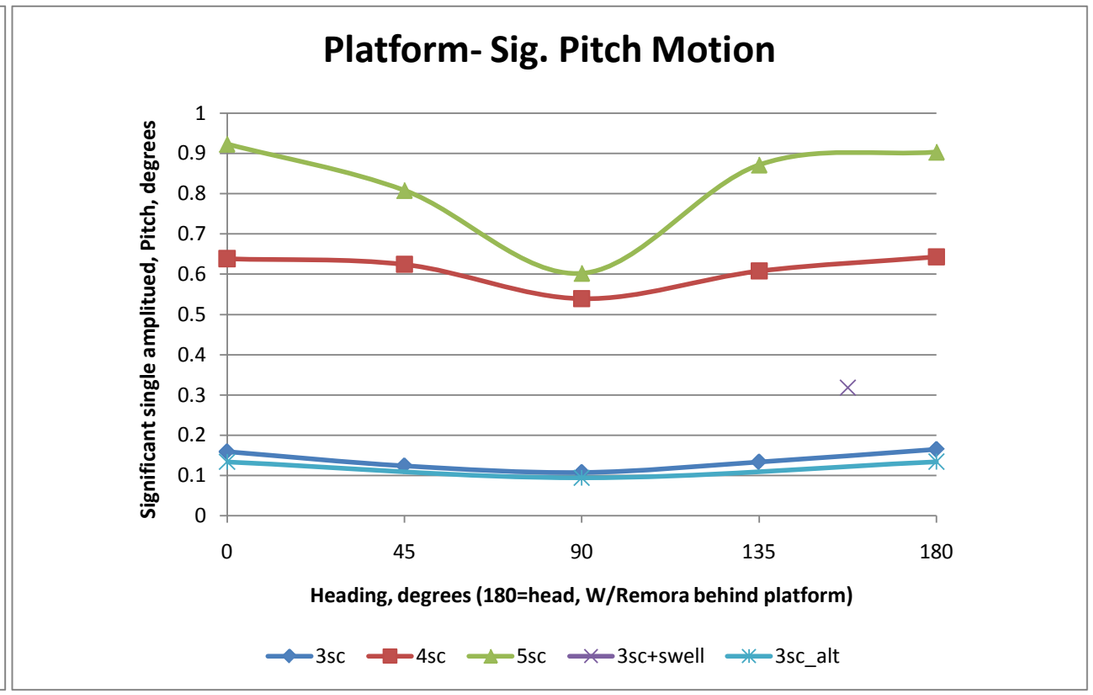
Case	File*	Sea State	Heading	Avg_heave	Avg_roll	Avg_pitch	rms_heave	rms_roll	rms_pitch	acc in mpss rms_Heave_ac	acc in g's rms_Heave_	sig_heave	Sig_roll	Sig_pitch
Case 1- Remora	ss3sc_0kt_000	3sc	0	-3.71E+01	-9.30E-03	-2.08E-03	7.26E-02	3.81E-02	5.33E-02	3.18E-02	3.24E-03	1.48E-01	7.15E-02	1.15E-01
Case 2- Remora	ss3sc_0kt_045	3sc	45	-3.71E+01	1.10E-03	1.22E-03	7.97E-02	5.00E-02	4.84E-02	3.15E-02	3.21E-03	1.58E-01	9.92E-02	9.46E-02
Case 3- Remora	ss3sc_0kt_090	3sc	90	-3.71E+01	6.60E-04	1.88E-03	5.78E-02	5.76E-02	7.82E-02	2.46E-02	2.51E-03	1.16E-01	1.15E-01	1.48E-01
Case 4- Remora	ss3sc_0kt_135	3sc	135	-3.71E+01	4.94E-03	2.93E-03	6.57E-02	4.44E-02	5.63E-02	3.00E-02	3.06E-03	1.31E-01	8.75E-02	1.09E-01
Case 5- Remora	ss3sc_0kt_180	3sc	180	-3.71E+01	7.31E-03	8.89E-03	5.61E-02	3.72E-02	3.94E-02	2.61E-02	2.66E-03	1.16E-01	6.46E-02	7.45E-02
Case 6- Remora	ss4sc_0kt_000	4sc	0	-3.71E+01	-7.90E-03	-2.98E-03	3.31E-01	7.65E-02	1.41E-01	9.85E-02	1.00E-02	6.60E-01	1.43E-01	2.85E-01
Case 7- Remora	ss4sc_0kt_045	4sc	45	-3.71E+01	1.77E-03	-6.38E-03	3.33E-01	9.32E-02	2.94E-01	9.95E-02	1.02E-02	6.49E-01	1.83E-01	5.56E-01
Case 8- Remora	ss4sc_0kt_090	4sc	90	-3.71E+01	3.29E-04	-1.38E-02	3.47E-01	1.24E-01	1.70E-01	9.60E-02	9.79E-03	6.92E-01	2.49E-01	3.34E-01
Case 9- Remora	***ss4sc_0kt_135***	***4sc***	***135***	-3.71E+01	6.22E-03	6.68E-03	3.53E-01	9.54E-02	2.12E-01	1.03E-01	1.05E-02	6.79E-01	1.89E-01	4.02E-01
Case 10- Remora	ss4sc_0kt_180	4sc	180	-3.71E+01	1.76E-02	1.03E-02	3.43E-01	7.40E-02	2.06E-01	9.45E-02	9.63E-03	6.68E-01	1.30E-01	3.95E-01
Case 11- Remora	ss5sc_0kt_000	5sc	0	-3.71E+01	-2.09E-02	2.35E-02	8.80E-01	1.43E-01	6.61E-01	2.43E-01	2.48E-02	1.78E+00	2.71E-01	1.25E+00
Case 12- Remora	ss5sc_0kt_045	5sc	45	-3.71E+01	-8.53E-03	-6.13E-03	9.24E-01	2.31E-01	8.94E-01	2.55E-01	2.60E-02	1.69E+00	4.37E-01	1.63E+00
Case 13- Remora	ss5sc_0kt_090	5sc	90	-3.71E+01	-1.97E-02	-3.03E-02	9.46E-01	2.93E-01	5.10E-01	2.50E-01	2.55E-02	1.76E+00	5.55E-01	1.00E+00
Case 14- Remora	ss5sc_0kt_135	5sc	135	-3.71E+01	1.45E-03	5.07E-03	8.46E-01	1.94E-01	5.28E-01	2.37E-01	2.42E-02	1.69E+00	3.84E-01	9.81E-01
Case 15- Remora	ss5sc_0kt_180	5sc	180	-3.71E+01	4.18E-02	2.82E-02	6.64E-01	1.77E-01	3.41E-01	1.90E-01	1.94E-02	1.32E+00	3.11E-01	6.07E-01
Case 16- Remora	ss3sc_swell__0kt_18(	3sc+swell	157.5	-3.71E+01	-2.89E-02	-8.02E-02	1.44E+00	1.07E-01	3.37E-01	3.22E-01	3.29E-02	2.66E+00	2.10E-01	6.28E-01
Case 17- Remora	ss3sc-ss_0kt_000	3sc_alt	0	-3.71E+01	-1.25E-02	-3.82E-03	3.25E-02	5.26E-02	6.28E-02	2.05E-02	2.09E-03	6.70E-02	9.27E-02	1.15E-01
Case 18- Remora	ss3sc-ss_0kt_090	3sc_alt	90	-3.71E+01	4.50E-03	-4.88E-03	2.74E-02	4.82E-02	1.75E-01	1.52E-02	1.55E-03	5.43E-02	9.85E-02	3.50E-01
Case 19- Remora	ss3sc-ss_0kt_180	3sc_alt	180	-3.71E+01	9.97E-03	1.16E-02	2.48E-02	3.82E-02	1.06E-01	1.60E-02	1.63E-03	4.97E-02	6.60E-02	1.94E-01

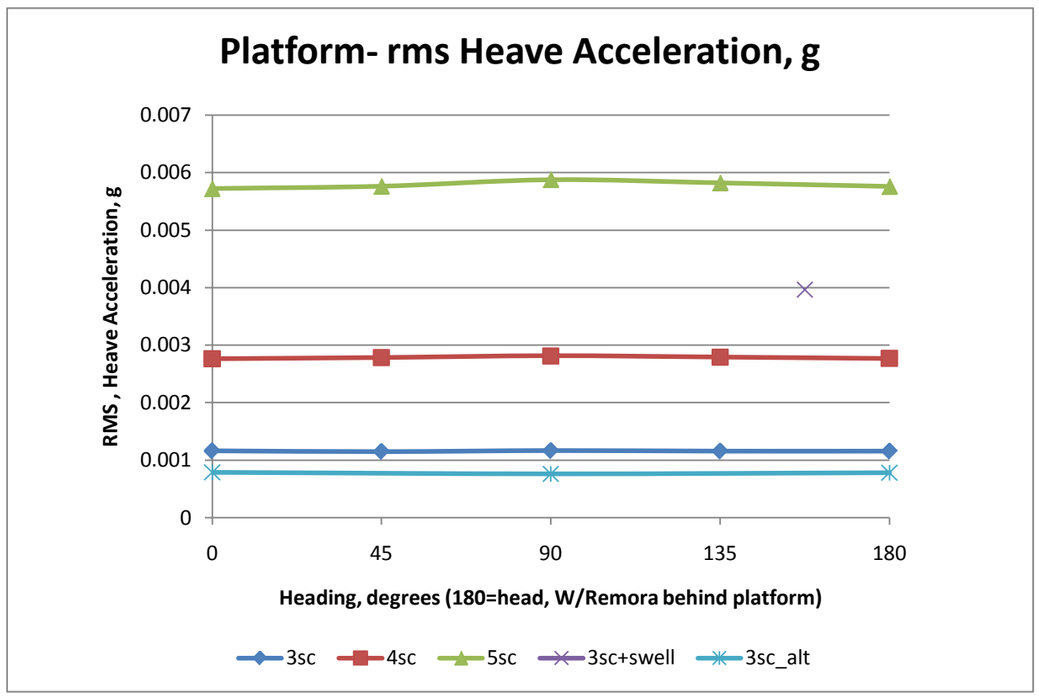
Case	File*	Sea State	Heading	Min_heave	Min_roll	Min_pitch	acc in mpss Min_Zacc	acc in g's Min_Zacc	Max_heave	Max_roll	Max_pitch	acc in mpss Max_Zacc	acc in g's Max_Zacc
Case 1- Pla	ss3sc_0kt_	3sc	0	-8.08015	-8.85E-02	-0.225336	-3.67E-02	-0.0037	-7.93411	0.148522	0.203839	3.35E-02	0.0034
Case 2- Pla	ss3sc_0kt_	3sc	45	-8.08192	-0.17285	-0.167216	-3.51E-02	-0.0036	-7.93	0.17293	0.201548	3.28E-02	0.0033
Case 3- Pla	ss3sc_0kt_	3sc	90	-8.08097	-0.214397	-0.161751	-3.66E-02	-0.0037	-7.93241	0.206859	0.232058	3.25E-02	0.0033
Case 4- Pla	ss3sc_0kt_	3sc	135	-8.0828	-0.198571	-0.15803	-3.57E-02	-0.0036	-7.92917	0.160351	0.224736	3.27E-02	0.0033
Case 5- Pla	ss3sc_0kt_	3sc	180	-8.08078	-0.149108	-0.21242	-3.59E-02	-0.0037	-7.93463	8.84E-02	0.221516	3.12E-02	0.0032
Case 6- Pla	ss4sc_0kt_	4sc	0	-8.19547	-0.228158	-0.784444	-7.24E-02	-0.0074	-7.80358	0.397468	0.84111	7.32E-02	0.0075
Case 7- Pla	ss4sc_0kt_	4sc	45	-8.19296	-0.418116	-0.820409	-7.66E-02	-0.0078	-7.8024	0.389698	0.76949	7.30E-02	0.0074
Case 8- Pla	ss4sc_0kt_	4sc	90	-8.20428	-0.5552	-0.73921	-7.36E-02	-0.0075	-7.79929	0.43189	0.896445	7.45E-02	0.0076
Case 9- Pla	ss4sc_0kt_	4sc	135	-8.1978	-0.538206	-0.743467	-7.93E-02	-0.0081	-7.79753	0.342298	0.706682	7.56E-02	0.0077
Case 10- Pl	ss4sc_0kt_	4sc	180	-8.19683	-0.400562	-0.843384	-7.44E-02	-0.0076	-7.79638	0.22708	0.797767	7.34E-02	0.0075
Case 11- Pl	ss5sc_0kt_	5sc	0	-8.52038	-0.547844	-1.55528	-0.17902	-0.0183	-7.31638	0.919121	1.83739	0.188348	0.0192
Case 12- Pl	ss5sc_0kt_	5sc	45	-8.51307	-0.912584	-1.12596	-0.179738	-0.0183	-7.305	0.934491	1.44251	0.186068	0.0190
Case 13- Pl	ss5sc_0kt_	5sc	90	-8.548	-1.28672	-0.633369	-0.179936	-0.0183	-7.29362	0.783298	1.12831	0.197929	0.0202
Case 14- Pl	ss5sc_0kt_	5sc	135	-8.51801	-1.16805	-1.4038	-0.178347	-0.0182	-7.31535	0.629225	1.51427	0.189567	0.0193
Case 15- Pl	ss5sc_0kt_	5sc	180	-8.52112	-0.913076	-1.84018	-0.177517	-0.0181	-7.314	0.554089	1.57537	0.190293	0.0194
Case 16- Pl	ss3sc_swel	3sc+swell	180+135	-8.4706	-0.48964	-0.510908	-0.105616	-0.0108	-7.50714	0.357959	0.473434	0.104637	0.0107
Case 17- Pl	ss3sc-ss_0l	3sc_alt	0	-8.04114	-7.08E-02	-0.207405	-1.90E-02	-0.0019	-7.9745	0.110193	0.220039	2.18E-02	0.0022
Case 18- Pl	ss3sc-ss_0l	3sc_alt	90	-8.03955	-0.155405	-0.115638	-1.72E-02	-0.0018	-7.97526	0.130587	0.162026	1.97E-02	0.0020
Case 19- Pl	ss3sc-ss_0l	3sc_alt	180	-8.03952	-0.110439	-0.215808	-1.78E-02	-0.0018	-7.97574	6.98E-02	0.209066	2.01E-02	0.0020

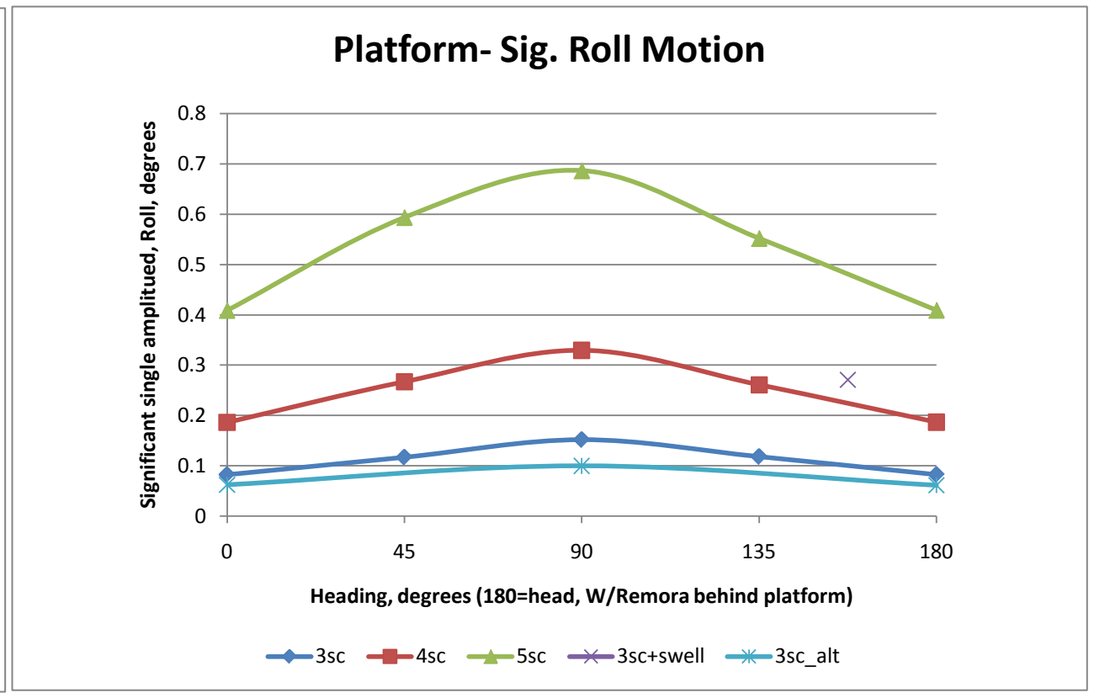
Case	File*	Sea State	Heading	Min_heave	Min_roll	Min_pitch	acc in mpss Min_Zacc	acc in g's Min_Zacc	Max_heave	Max_roll	Max_pitch	acc in mpss Max_Zacc	acc in g's Max_Zacc
Case 1- Rer	ss3sc_0kt_	3sc	0	-37.3299	-0.124155	-0.157462	-0.10091	-0.0103	-36.8991	8.77E-02	0.141286	9.13E-02	0.0093
Case 2- Rer	ss3sc_0kt_	3sc	45	-37.3392	-0.156692	-0.116017	-8.87E-02	-0.0090	-36.8926	0.139416	0.158709	9.06E-02	0.0092
Case 3- Rer	ss3sc_0kt_	3sc	90	-37.3235	-0.185907	-0.173129	-0.104696	-0.0107	-36.8846	0.189862	0.169306	8.40E-02	0.0086
Case 4- Rer	ss3sc_0kt_	3sc	135	-37.3112	-0.105823	-0.12973	-8.61E-02	-0.0088	-36.9119	0.150024	0.161614	7.91E-02	0.0081
Case 5- Rer	ss3sc_0kt_	3sc	180	-37.2716	-8.49E-02	-9.13E-02	-7.21E-02	-0.0073	-36.9549	0.11432	0.13378	7.21E-02	0.0073
Case 6- Rer	ss4sc_0kt_	4sc	0	-38.0564	-0.216526	-0.425558	-0.314913	-0.0321	-36.169	0.193857	0.494704	0.287657	0.0293
Case 7- Rer	ss4sc_0kt_	4sc	45	-38.0932	-0.254169	-0.586078	-0.286564	-0.0292	-36.148	0.265252	0.669677	0.276431	0.0282
Case 8- Rer	ss4sc_0kt_	4sc	90	-38.0884	-0.417497	-0.419895	-0.257059	-0.0262	-36.2081	0.338974	0.411772	0.271431	0.0277
Case 9- Rer	ss4sc_0kt_	4sc	135	-37.979	-0.236525	-0.60893	-0.330112	-0.0337	-36.1763	0.307882	0.508315	0.266426	0.0272
Case 10- Re	ss4sc_0kt_	4sc	180	-38.0071	-0.191492	-0.681996	-0.277922	-0.0283	-36.1769	0.258957	0.424431	0.277862	0.0283
Case 11- Re	ss5sc_0kt_	5sc	0	-39.5462	-0.517103	-1.39631	-0.785001	-0.0800	-34.6357	0.420263	1.70826	0.712473	0.0727
Case 12- Re	ss5sc_0kt_	5sc	45	-39.3692	-0.753397	-1.92601	-0.677614	-0.0691	-35.0844	0.765419	1.85703	0.70735	0.0721
Case 13- Re	ss5sc_0kt_	5sc	90	-39.3033	-0.989171	-1.36263	-0.671392	-0.0685	-34.8771	0.798365	1.31973	0.616708	0.0629
Case 14- Re	ss5sc_0kt_	5sc	135	-39.438	-0.567609	-1.32899	-0.627216	-0.0640	-34.932	0.635273	1.16023	0.674448	0.0688
Case 15- Re	ss5sc_0kt_	5sc	180	-39.1678	-0.363356	-1.14027	-0.667709	-0.0681	-35.0651	0.522175	0.940692	0.598511	0.0610
Case 16- Re	ss3sc_swel	3sc+swell	180+135	-40.3952	-0.396545	-1.20062	-0.766553	-0.0782	-33.6541	0.218255	0.602094	0.746779	0.0761
Case 17- Re	ss3sc-ss_0l	3sc_alt	0	-37.2068	-0.184163	-0.161008	-6.70E-02	-0.0068	-37.0037	0.146431	0.142097	6.28E-02	0.0064
Case 18- Re	ss3sc-ss_0l	3sc_alt	90	-37.2049	-0.141793	-0.379312	-4.26E-02	-0.0043	-37.0234	0.170902	0.403509	4.52E-02	0.0046
Case 19- Re	ss3sc-ss_0l	3sc_alt	180	-37.1815	-0.102299	-0.208866	-4.67E-02	-0.0048	-37.0425	0.139736	0.218877	4.71E-02	0.0048

MultiPlatform5_ss4sc_0kt_135	STATS	X	Y	Z	Roll	Pitch
Relative	rms	0.219	0.113	0.381	0.173	0.342
REMORA				0.353	0.095	0.212
PLATFORM				0.071	0.134	0.314

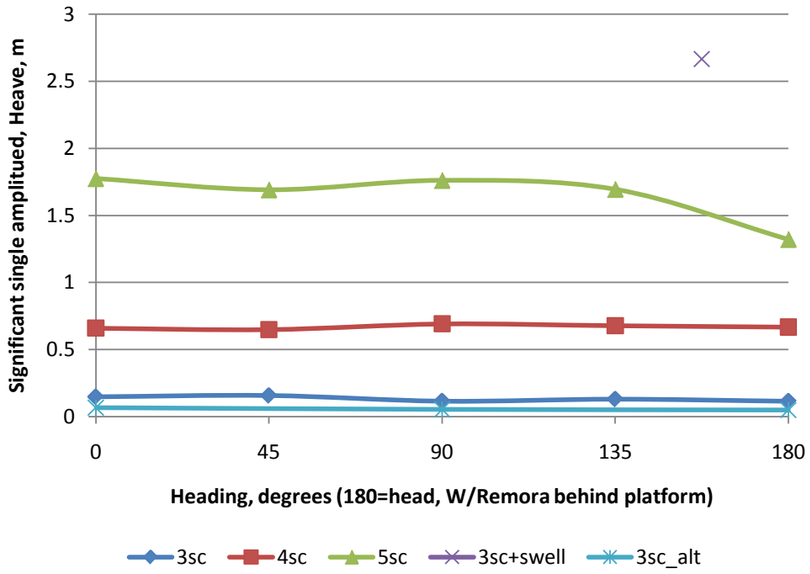




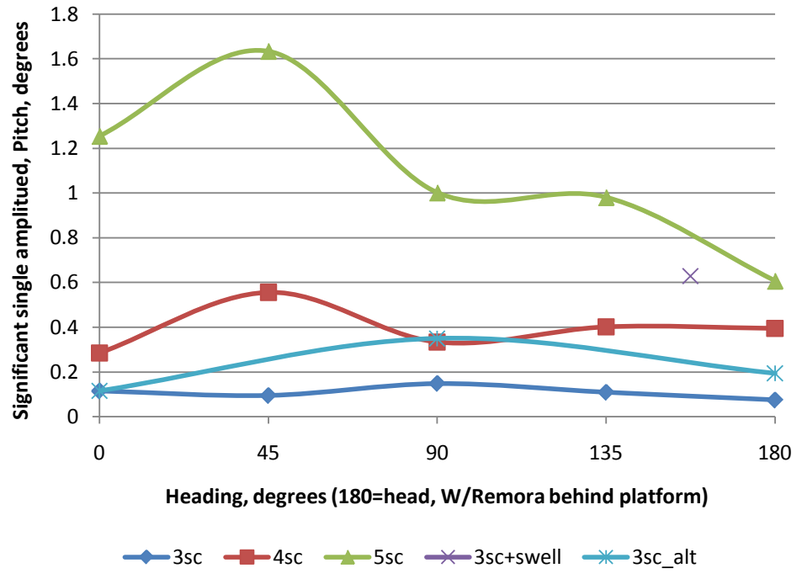




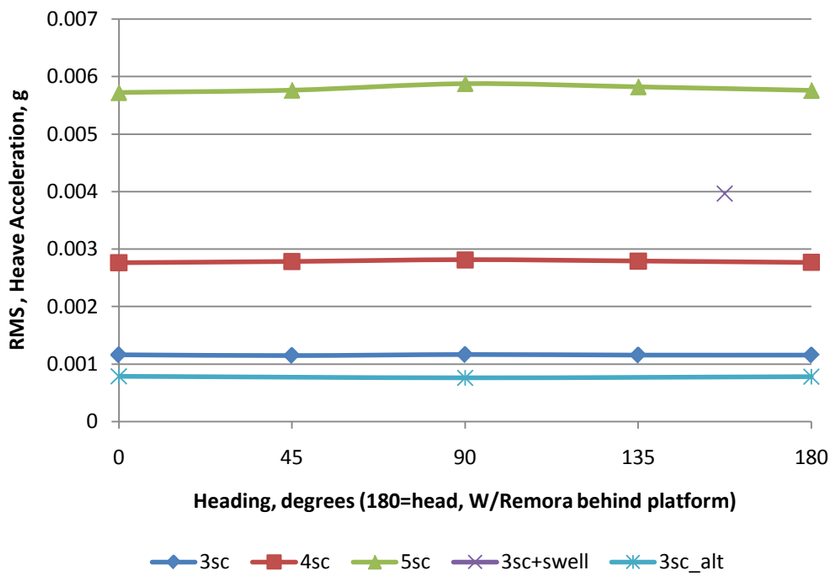
Remora- Sig. Heave Motion, m



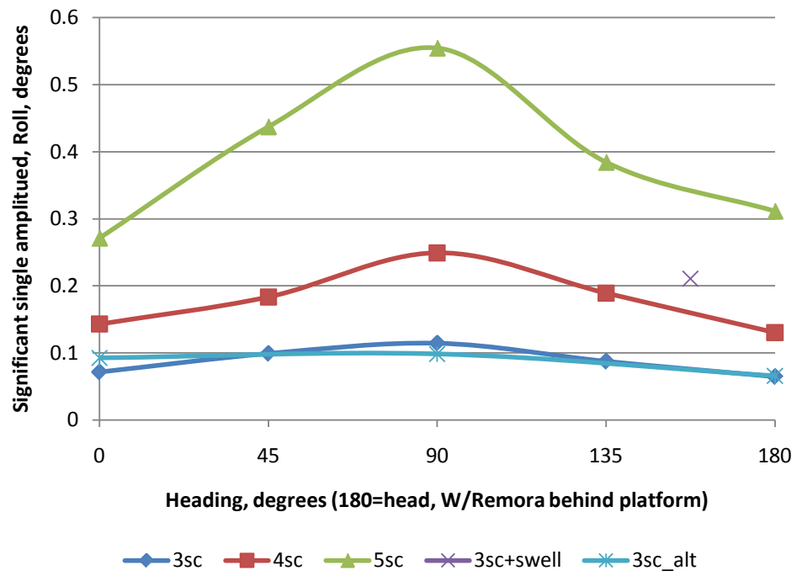
Remora- Sig. Pitch Motion



Remora- rms Heave Acceleration, g



Remora- Sig. Roll Motion



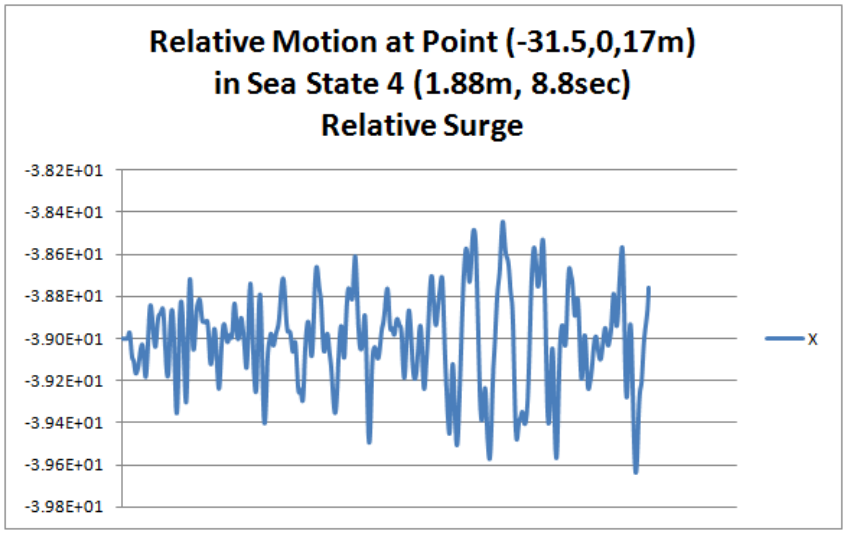
Remora Iteration 2.1

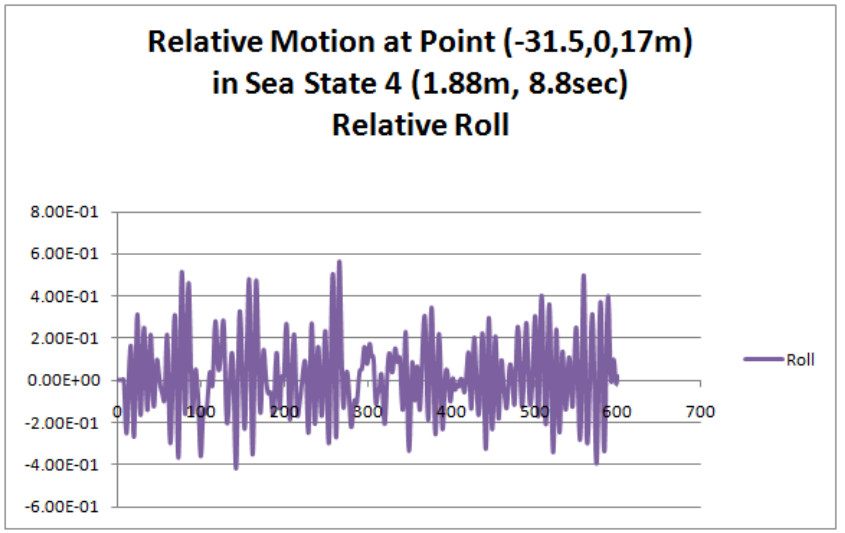
LAMP Run

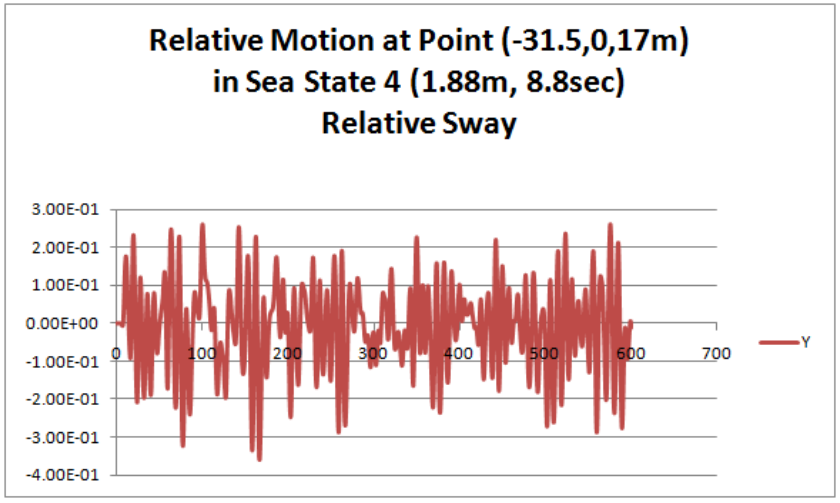
MultiPlatform5_ss4sc_0kt_135-pt1-relativemot

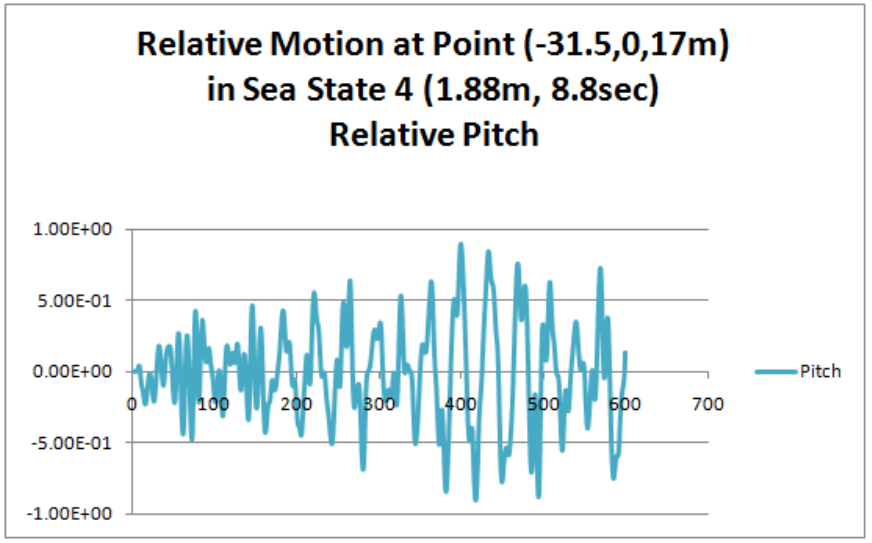
STATS	X	Y	Z	Roll	Pitch
rms	0.219	0.113	0.381	0.173	0.342
4*rms	0.877	0.453	1.523	0.692	1.367
MAX	-38.443	0.261	1.103	0.564	0.899
MIN	-39.637	-0.358	-0.958	-0.420	-0.908

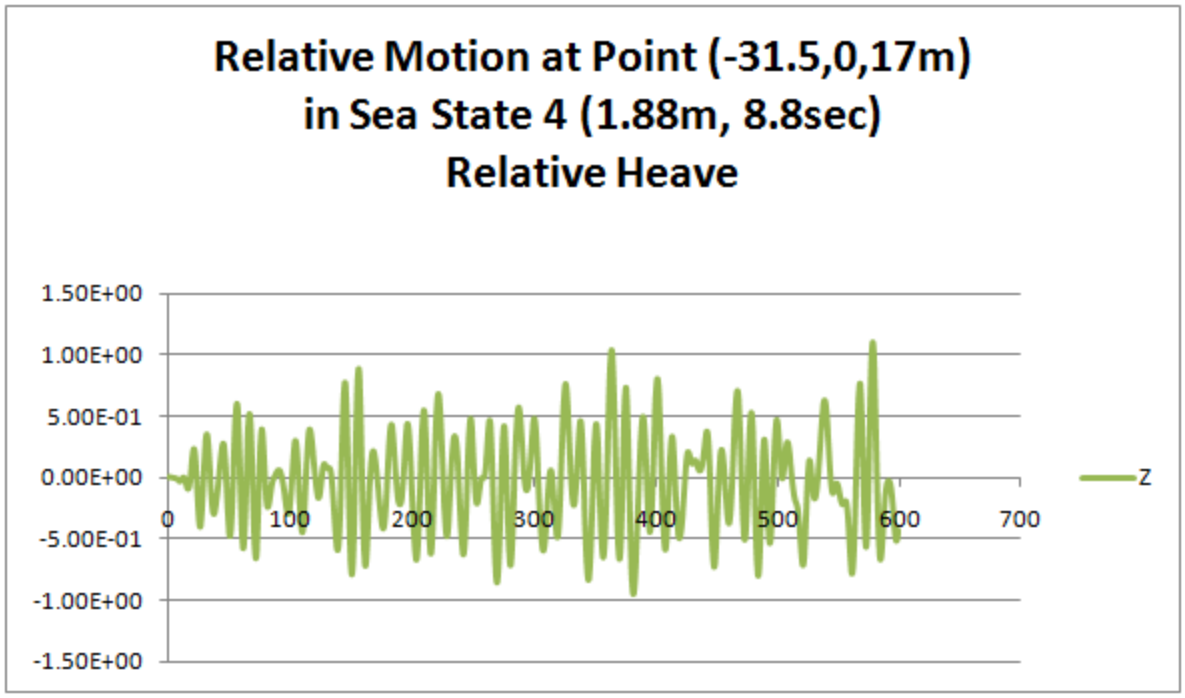
STATS	X	Y	Z	Roll	Pitch
rms	0.219	0.113	0.381	0.173	0.342
4*rms	0.877	0.453	1.523	0.692	1.367









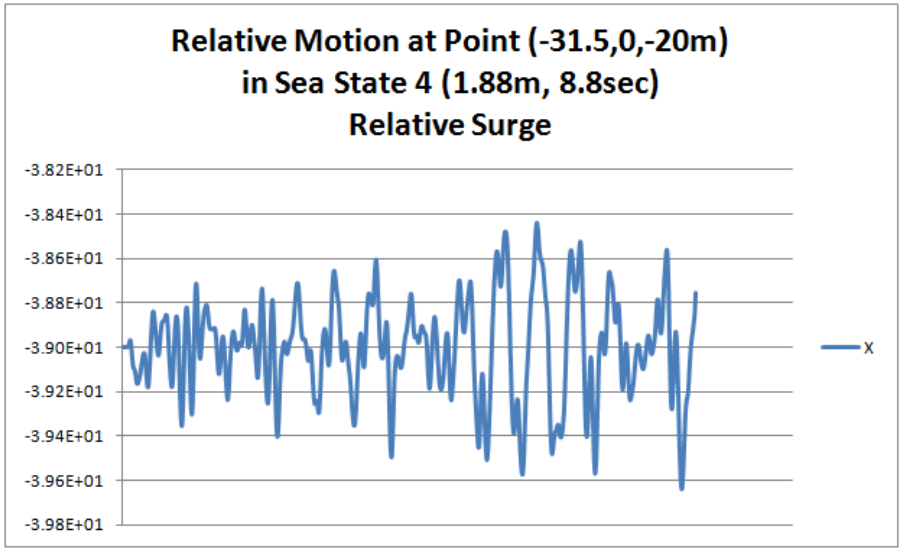

Relative Motion at Point (-31.5,0,17m)
in Sea State 4 (1.88m, 8.8sec)
Relative Heave
1.50E+00
1.00E+00
5.00E-01
0.00E+00
-5.00E-01
-1.00E+00
-1.50E+00
0
100
200
300
400
500
600
700
Z

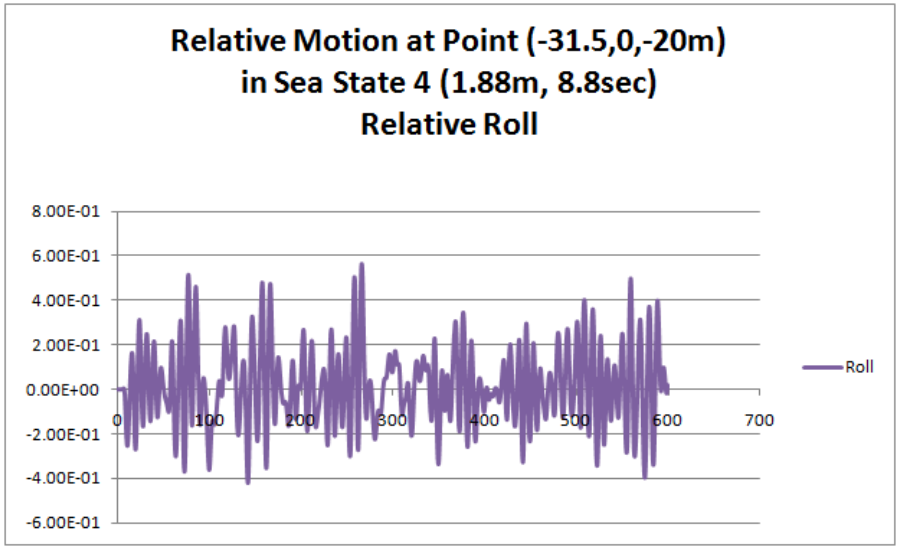
Remora Iteration 2.1

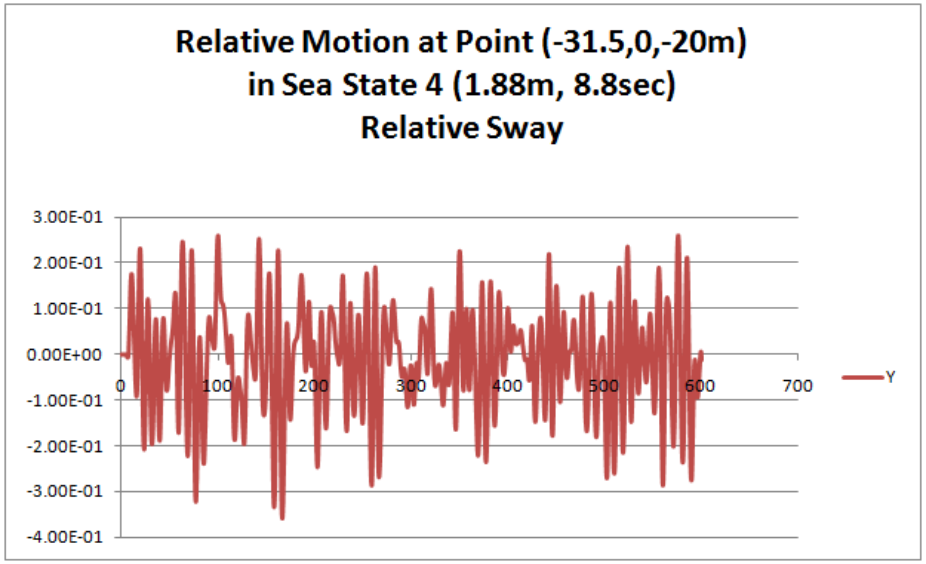
LAMP Run

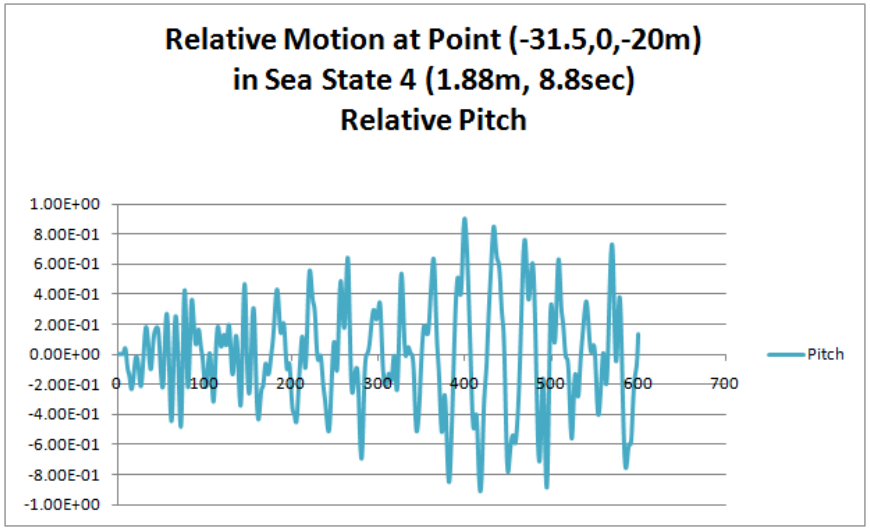
MultiPlatform5_ss4sc_0kt_135-pt2-relativemot

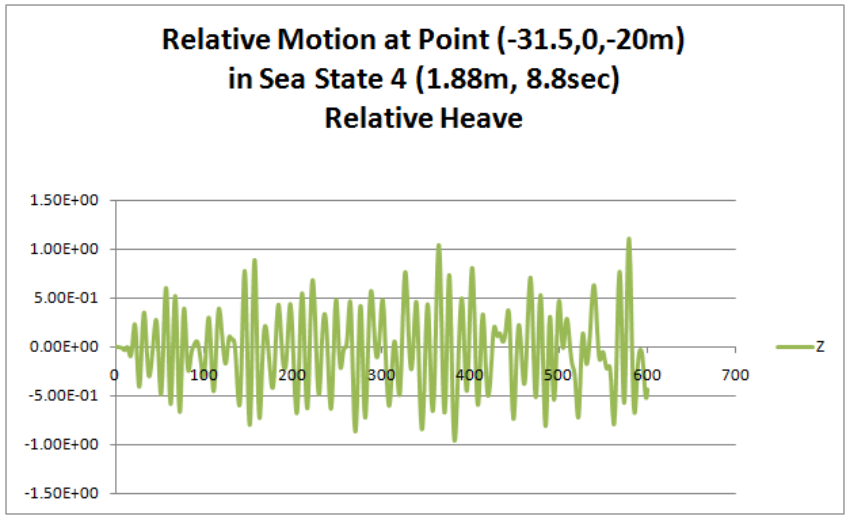
STATS	X	Y	Z	Roll	Pitch
rms	0.219	0.113	0.381	0.173	0.342
4*rms	0.877	0.453	1.523	0.692	1.367









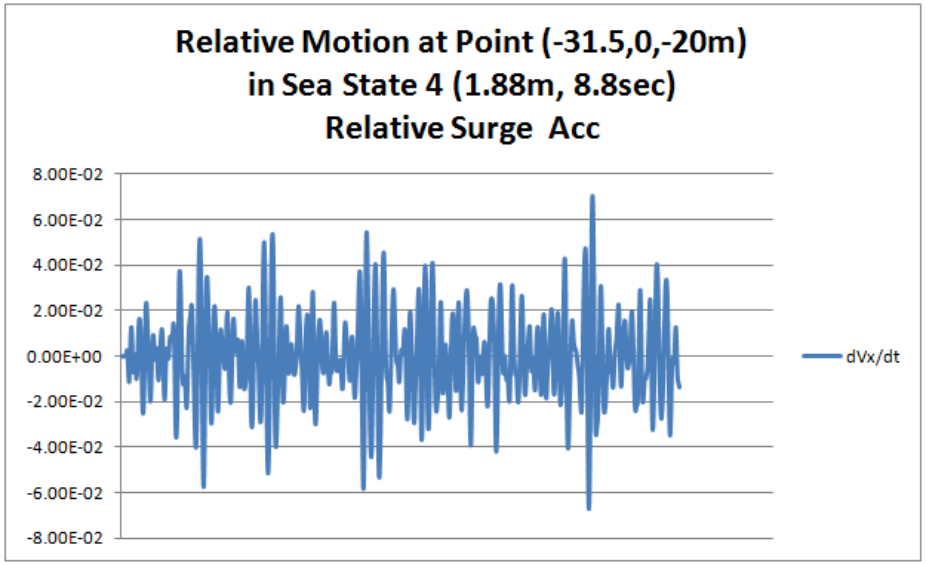

Relative Motion at Point (-31.5,0,-20m)
in Sea State 4 (1.88m, 8.8sec)
Relative Heave
1.50E+00
1.00E+00
5.00E-01
0.00E+00
-5.00E-01
-1.00E+00
-1.50E+00
0
100
200
300
400
500
600
700
Z

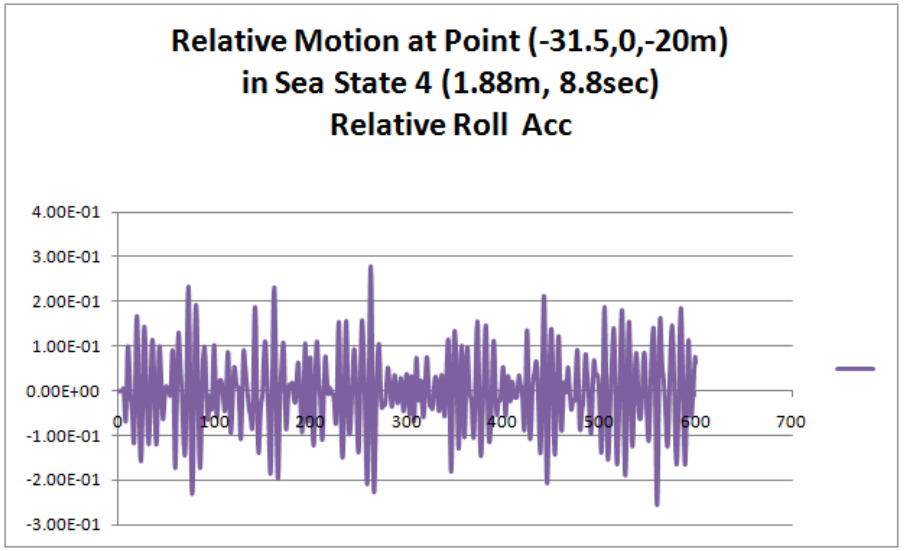
Remora Iteration 2.1

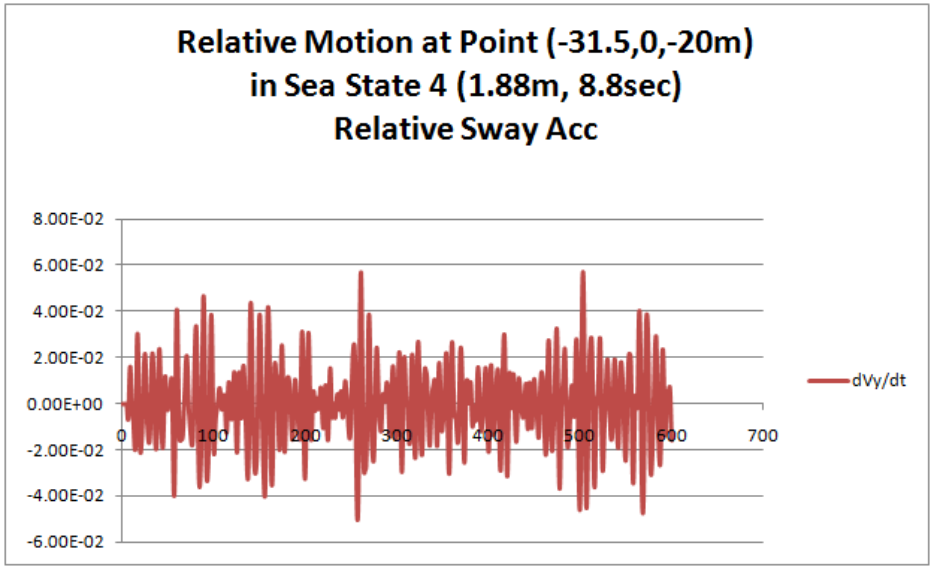
LAMP Run

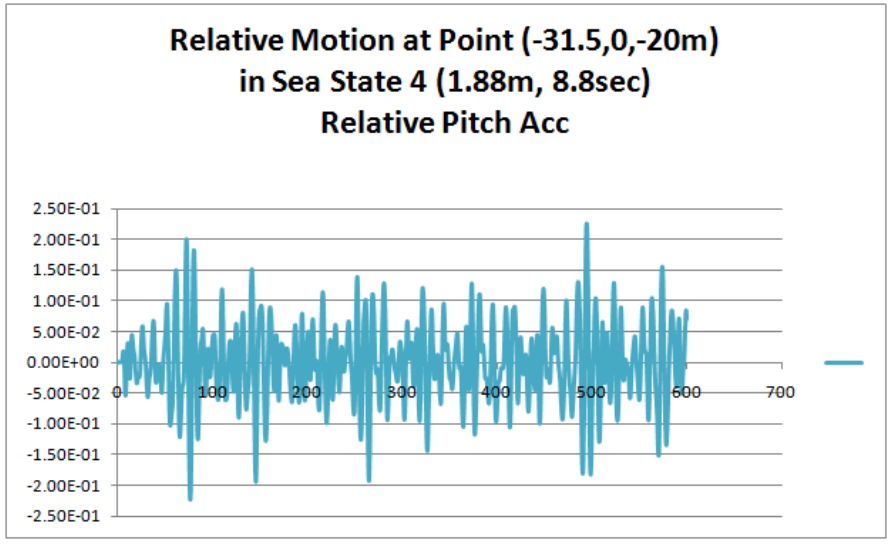
MultiPlatform5_ss4sc_0kt_135-pt2-relativeAcc

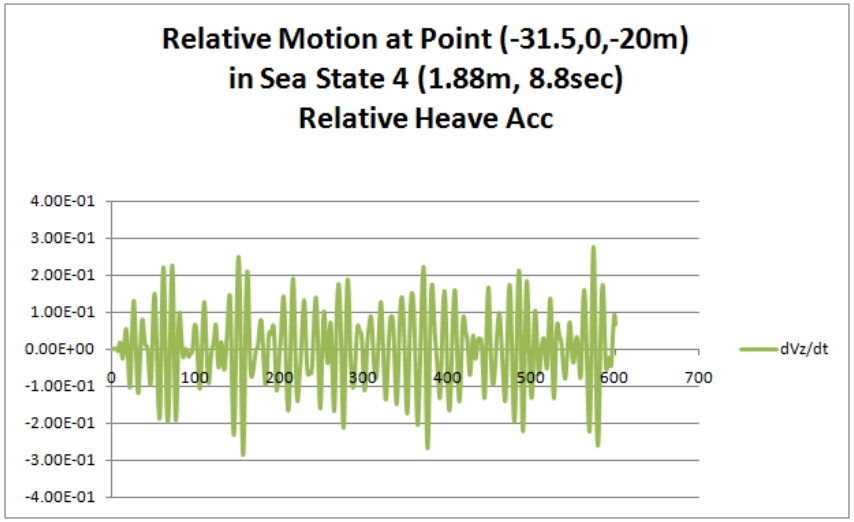
STATS	X	Y	Z	Roll	Pitch
rms	0.019	0.017	0.098	0.084	0.064
4*rms	0.078	0.068	0.394	0.334	0.256









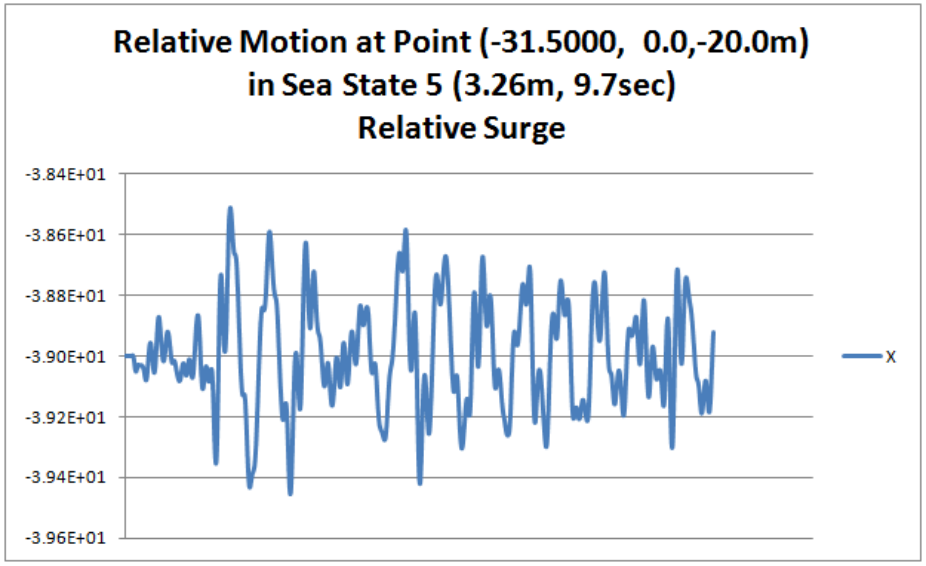

Relative Motion at Point (-31.5,0,-20m)
in Sea State 4 (1.88m, 8.8sec)
Relative Heave Acc
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
-1.00E-01
-2.00E-01
-3.00E-01
-4.00E-01
0
100
200
300
400
500
600
700
dVz/dt

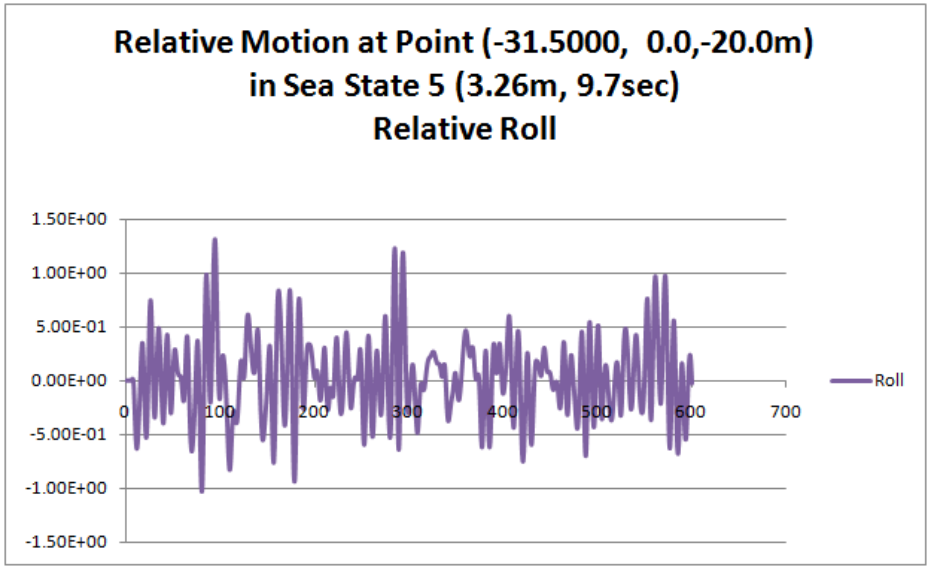
Remora Iteration 2.1

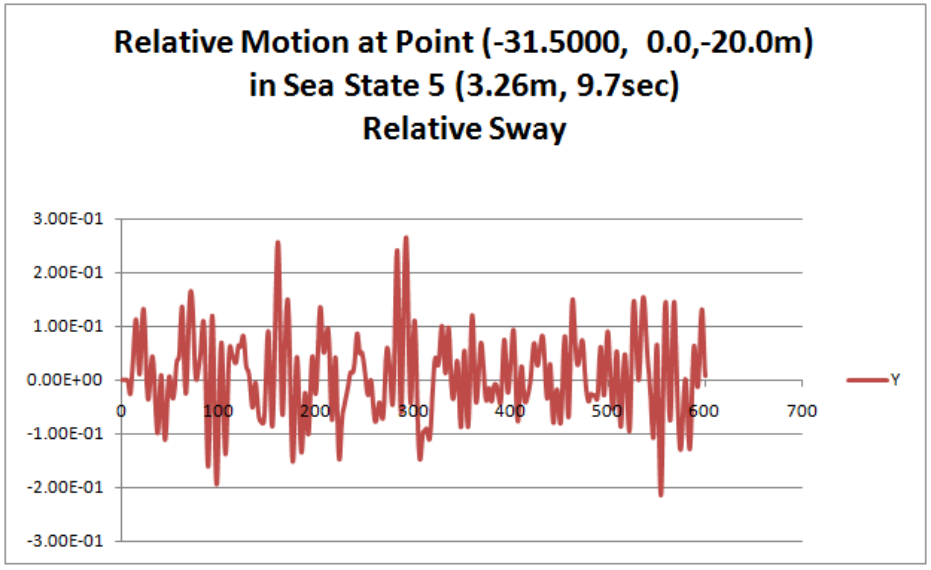
LAMP Run

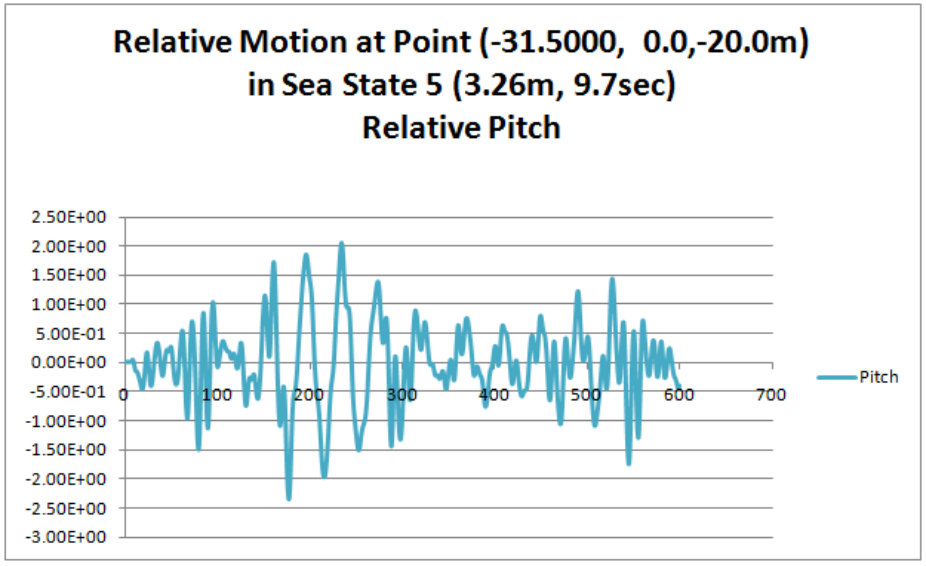
MultiPlatform5_ss5sc_0kt_135-relativemot

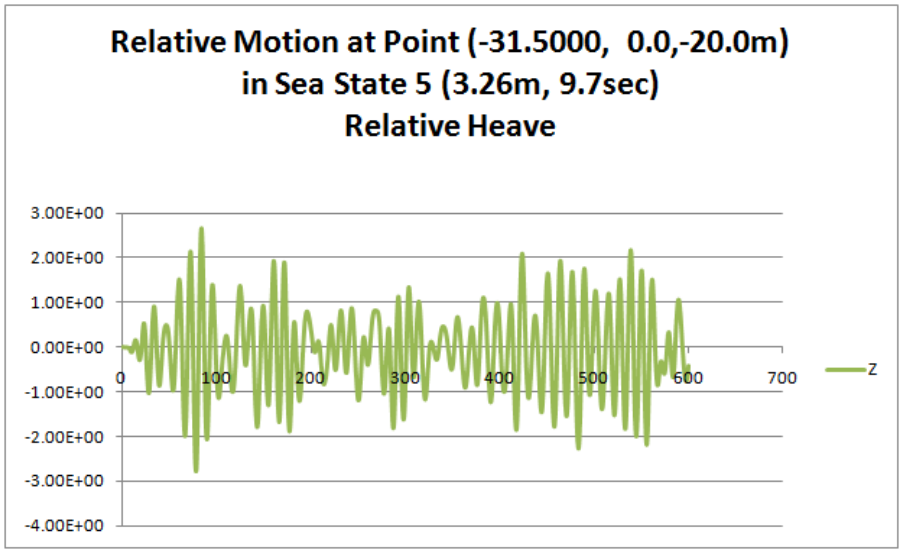
STATS	X	Y	Z	Roll	Pitch
rms	0.173	0.073	0.913	0.367	0.701
4*rms	0.694	0.293	3.650	1.469	2.802










Relative Motion at Point (-31.5000, 0.0,-20.0m)
in Sea State 5 (3.26m, 9.7sec)
Relative Heave
3.00E+00
2.00E+00
1.00E+00
0.00E+00
-1.00E+00
-2.00E+00
-3.00E+00
-4.00E+00
0
100
200
300
400
500
600
700
Z

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-23
Remora Scantling Review 1a
OTEC-2010-001

17 September 2010

Prepared for:

Naval Facilities Engineering Command
Naval Facilities Engineering Service Center (NFESC)
1100 23rd Avenue
Port Hueneme, CA 93043-4370
Attn: Mr. Brian Cable, Contracting Officer Representative

Prepared by:

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9500 Godwin Drive
Manassas, VA 20110

Distribution Statement A: Approved for public release; distribution is unlimited

Horton Wison Deepwater

Remora Scantling Review

OTEC MCF 18

Multi Column Floater (MCF) 18 at 23m Draft
Lockheed
Ocean Thermal Energy Conversion (OTEC)

Document No.: HWD10-021-17-3000						
Rev. No.	**Rev. Date**	**Revision Description**	**Prepared By:**	**Checked By:**	**Approved By:**	**Client Approval**
Original	22-Apr-10	For issue to client	RD	JVM	JVM	

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5 Configuration sketches 11

1 SCOPE

Horton Wison Deepwater (HWD) has been tasked to review and comment on the scantlings developed for the Remoras installed on the Multi-Column Floater (MCF) designed to support a 10 mega-watt Ocean Thermal Energy Conversion (OTEC) plant with installation planned for offshore Hawaii in a water depth of 1100 meters.

Presented in this report are alternative scantling sizes and configurations, design logic used to develop these alternative scantlings, and snapshots taken of the 3-D structural model resulting from this sizing exercise. Loads used to develop the alternate configurations are based on preliminary load estimates for horizontal tow, upending of the hull at site, and in place loads. The Remora overall dimensions are from the existing design documents provided. It is understood that these are currently being revised as the design process matures. Neither affects the purpose of this report which is to propose alternate framing methods that may provide a lighter weight structure and to provide a configuration which takes into account fabrication and lessons learned from truss spar design.



Figure 1-1 Framing Systems Components

2 REVIEW

The structural elements used to develop the hull structure for the Remoras are plate, vertical stiffeners, and ring frames (both vertical and horizontal). Design of the plate thickness for hydrostatic load is controlled by the aspect ratio of the plate and the minimum span. Spacing of the vertical stiffeners and the horizontal ring frames adjust these two parameters to achieve a reasonable plate thickness for the fabrication technique employed. Center to center spacing of the vertical stiffeners is the primary control for plate design and is determined by dividing the arc distance between vertical frames into equal distances.

The quantity of vertical frames is used to control the size of both vertical and horizontal frames. The horizontal frame spacing sets the span length of the vertical stiffener. The maximum vertical frame spacing is therefore set by the properties of the vertical stiffeners available to the fabricator. To minimize the frame property requirements, intermediate struts can be added as shown in Figure 2-1 to reduce the design span.

Use of the axial strut element placed on the center axis of the Remora as shown in Figure 2-1 reduces the design span of 15 meters on the decks to 7.5 meters with an even shorter effective span. The axial strut could be replaced by a cylindrical shell to provide a trunk for electrical and piping hull components.

This design exercise utilizes

1. America Bureau of Shipping (ABS); Rules for Building and Classing Mobile Offshore Drilling Units
2. America Bureau of Shipping (ABS); Rules for Building and Classing Steel Vessels
3. Det Norske Veritas (DNV); Classification 30.1 Buckling Strength Analysis
4. American Petroleum Institute (API); Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms – API RP 2A-WSD
5. American Petroleum Institute (API); Bulletin on Stability Design of Cylindrical Shells – API Bulletin 2U

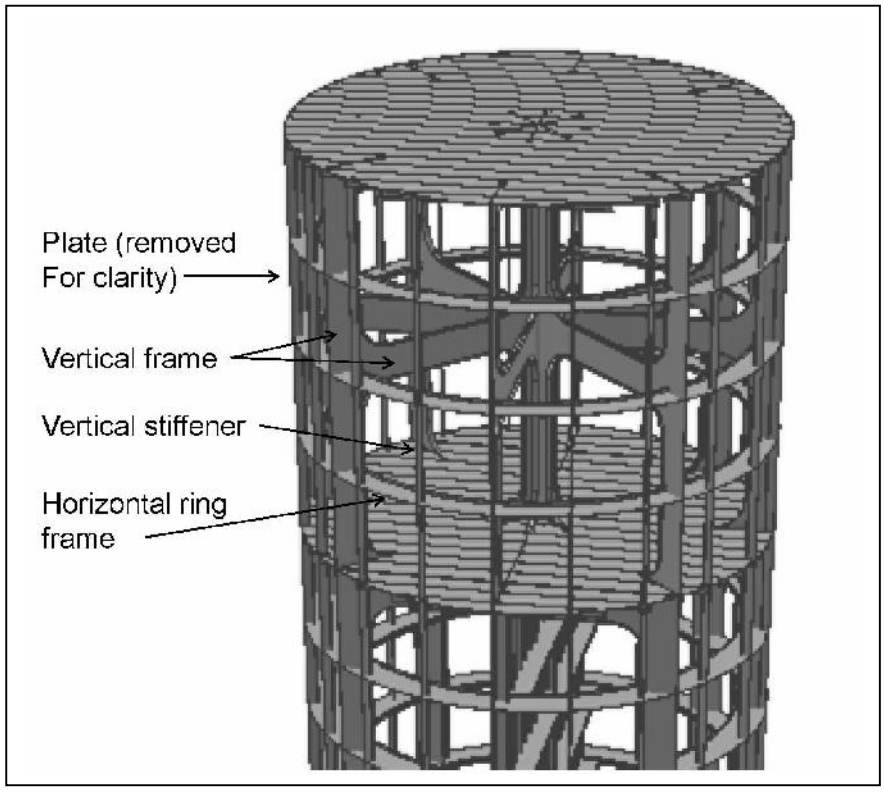


Figure 2-1 Vertical Girder and Bulkhead Arrangements

3 SUMMARY

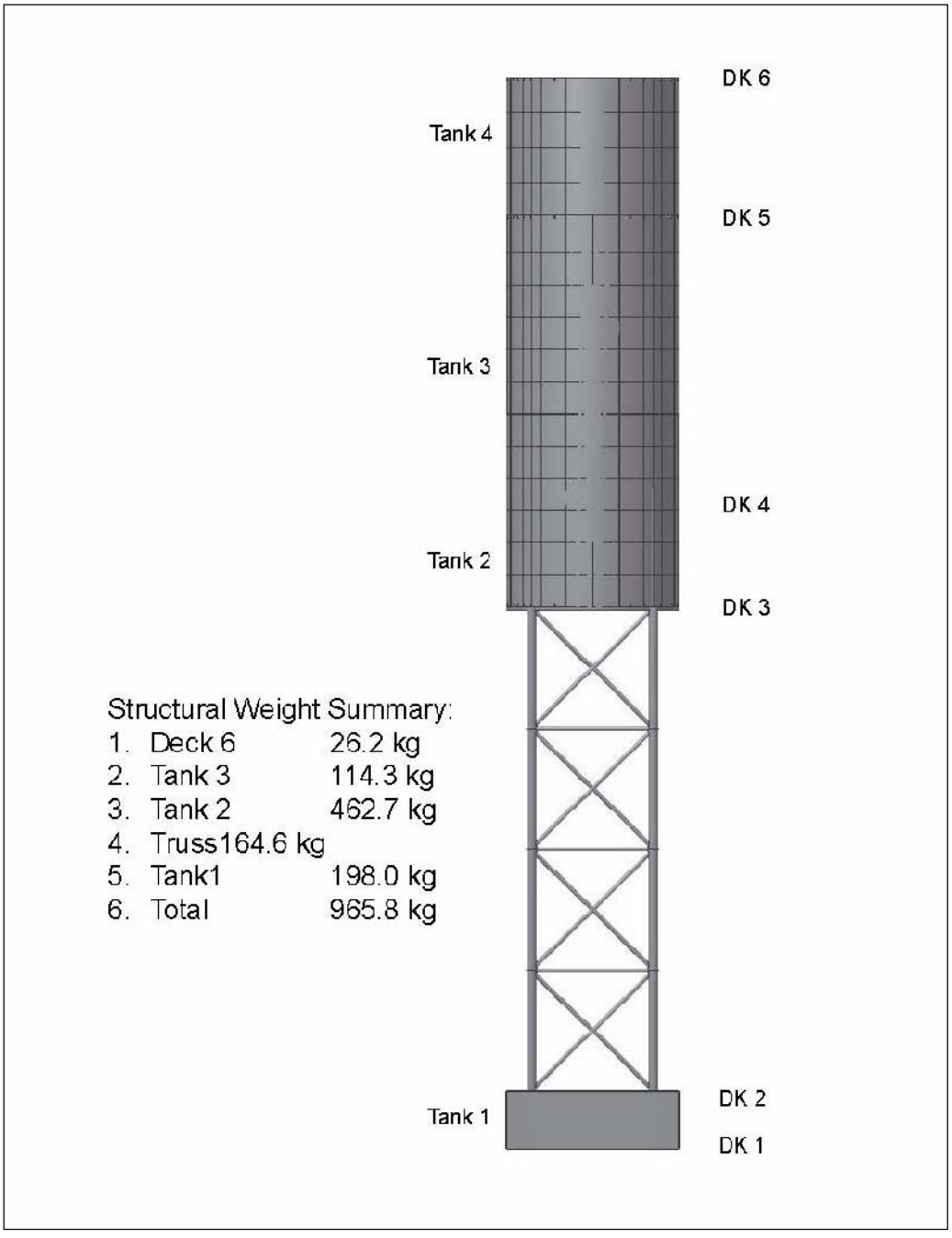


Figure 3-1 Outboard Profile with Component Weights

Table 3-1 Summary of scantling results are provided in the following tables

Keel (soft) Tank 1	Shell	Bulkhead	Bottom Deck	Upper Deck
Plate	19 mm	13mm	19 mm	19 mm
Stiffener	HP 240x11	HP180x10	HP 240x11	HP 240x11
Girder	T 991x13 / 254x16	T 635x10 / 254x16	T 1041x16 / 254x16	T 1041x16 / 254x16

Void Tank 2	Shell	Bulkhead	Bottom Deck	Upper Deck
Plate	19 mm	19mm	19 mm	19 mm
Stiffener	HP 240x11	HP240x11	HP 240x12	HP 240x12
Girder	T 787x13 / 203x13	T 965x16 / 356x19	T 610x13 / 203x13	T 610x13 / 203x13

Ballast Tank 3	Shell	Bulkhead	Upper Deck
Plate	19 mm	19mm	13 mm
Stiffener	HP 240x11	HP240x11	HP 180x10
Girder	T 787x13 / 203x13	T 965x16 / 356x19	T 533x10 / 152x10

Table 3-1 Continued

Ballast Tank 4	Shell	Bulkhead	Upper Deck
Plate	13 mm	13mm	13 mm
Stiffener	HP 200x9	HP180x8	HP 180x9
Girder	T 559x13 / 203x13	T 737x13 / 254x16	T 559x10 / 152x10

Ballast Tank 4	Shell	Bulkhead	Upper Deck
Plate	13 mm	13mm	13 mm
Stiffener	HP 200x9	HP180x8	HP 180x9
Girder	T 559x13 / 203x13	T 737x13 / 254x16	T 559x10 / 152x10

4 RECOMMENDATIONS

Horizontal bulkheads or decks used for compartmentation should be kept to a minimum. They increase the number of penetrations required by electrical and piping. During fabrication they have proven to be labor intensive and weight per unit area heavier than the alternative. If possible, provide compartmentation with vertical bulkheads. This also provides better control for marine operations i.e. trim during installation, control of the hull for tow.

The wedge shaped section removed from the upper hull will increase fabrication cost and will probably not offer significant weight reduction. If required for other functions it is constructible but may require special in cribbing and jigs.

On the Remora, the section near the waterline is the most likely to be damaged during operation. If a deck is added approximately 6 meters below the waterline, collision with a utility or supply boat compromising hull integrity is confined to smaller volumes. An additional deck may be considered above the cold water outlet. If leaks occur at the cold water penetration flooding effects will be minimized. Compartmentation requirements should address tow and installation functions and the load increase on Remora-hull support foundation in the event of accidental compartment flooding.

Although the following items are not structural, they need to be given consideration at this level of design:

1. Ballast piping requirements
2. Vent and sounding
3. Tanks access for regulatory marine inspection and possible hull repair
4. Foundations for equipment and structural connections

Table 3-1 summarizes the sizes of the structural components of the Remora hull structure.

5 CONFIGURATION SKETCHES

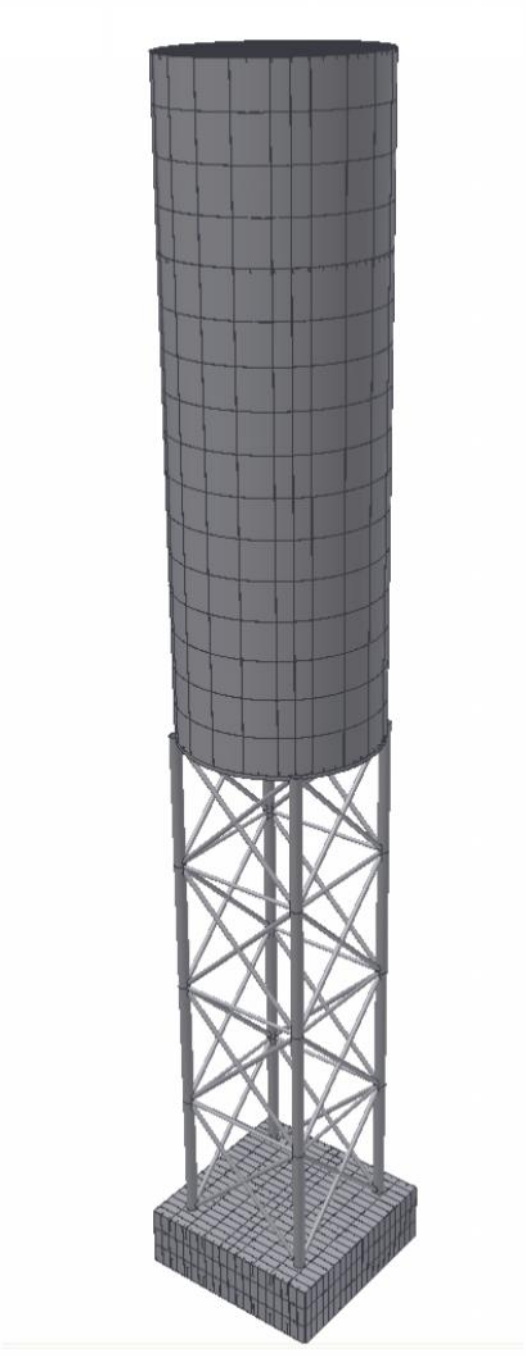


Figure 5-1 Remora Outboard Profile



Figure 5-2 Remora Half Section



Figure 5-3 Framing Skeleton (perspective view looking down)



Figure 5-4 Framing Skeleton (perspective view looking up)

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-24
Structure Calculations
OTEC-2010-001

17 September 2010

Prepared for:

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Distribution Statement A: Approved for public release; distribution is unlimited

APPENDIX 3.3.2.1.1-13

Remora Iteration 2.1—Detailed Structural Calculations & Summary

Remora Iteration 2.1

Detailed Structural Calculations

	Design Parameters						
		Overall					
			LOA (m)			85	
			OD (m)			15	
			Draft (m)				
		Upper Hull					
			LOA (m)			40	
			BOA (m)			13	
			Depth (m)			12.7	
		Mid-Secton					
			LOA (m)			45	
			BOA (m)			13	
			Depth (m)			12.7	
		Lower Hull					
			LOA (m)			5	
			BOA (m)			13	
			Depth (m)			12.7	
		Design Life (yrs)				20	
	Structural Loads						
3.2.3.1		Position Mooring System					
			100-yr Wave				
				Significant Height (m)			
				Period (s)			
			100-yr Wind				
				Speed (m/s)			
			100-yr Current				
				Speed (m/s)			
			Angular Separation (deg)				
3.2.3.3		Strength and Fatigue					
			100-yr Wave				
				Significant Height (m)		10.2	
				Period (s)		10.6	
				Length (m)		175.4288	
				Spectra			
				Swell Height (m)		4	
				Period (s)		20	

			100-yr Wind				
				Speed (m/s)			
			100-yr Current				
				Speed (m/s)		0.72	
3.2.3.3.3		Transit					
			10-yr Wave				
				Significant Height (m)			
				Period (s)			
				Spectra			
			10-yr Wind				
				Speed (m/s)			
			10-yr Current				
				Speed (m/s)			
3.2.4.3	Environmental Loads						
		Temperatures					
			Air				
				Max (deg C)			
				Min (deg C)			
			Water				
				WSW Max (deg C)		25.7	
				WSW Min (deg C)			
				DSW Max (deg C)		4.1	
				DSW Min (deg C)			
		Required Documentation					
		3.2.4.1		Environmental Report			
		3.3.1.1		Design Documentation			
					Reports		
					Calculations		
					Plans		
		3.3.1.3		Lightweight Data			
					CG		
					Inclining Test		
		3.3.1.5		Load Lline			
		3.3.1.7		Loading Manual			
		3.3.1.9		Trim and Stability Book			
		5B.3.2.1.1		Intact and Damaged Stability Analysis			
		5B.3.2.3		Watertight Plan			
		5B.3.3.5.1		Structural Strength			
		5B.3.3.5.1.2		Global Strength Analysis			

										Void	
UPPER HULL			UH OD (mm)		15000					Tank	
					Compt 1	Compt 2	Compt 3	Compt 4	Compt 5		Compt 6
			UH Compt Ht (mm)		5000	5000	12500	7500	10000	40000	10000
Plate											
Stiffs per panel	10	16	20	30	40	50	60	64			
Radial Spacing (mm)	4712.39	2945.24	2356.19	1570.80	1178.10	942.48	785.40	736.31			
α											
Compt 1	1.061	1.698	2.122	3.183	4.244	5.305	6.366	6.791			
Compt 2	1.061	1.698	2.122	3.183	4.244	5.305	6.366	6.791			
Compt 3	2.653	4.244	5.305	7.958	10.610	13.263	15.915	16.977			
Compt 4	1.592	2.546	3.183	4.775	6.366	7.958	9.549	10.186			
Compt 5	2.122	3.395	4.244	6.366	8.488	10.610	12.732	13.581			
Compt 6	2.122	3.395	4.244	6.366	8.488	10.610	12.732	13.581			
k											
Compt 1	0.818	0.980	1.000	1.000	1.000	1.000	1.000	1.000			
Compt 2	0.818	0.980	1.000	1.000	1.000	1.000	1.000	1.000			
Compt 3	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000			
Compt 4	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000			
Compt 5	1.004	1.000	1.000	1.000	1.000	1.000	1.000	1.000			
Compt 5	1.004	1.000	1.000	1.000	1.000	1.000	1.000	1.000			

		Hull Structural Steel							
			Higher Strength						
		Ordinary	AH32	AH36	AH40				
	Y (N/mm^2)	235	315	355	390				
	Y (psi)	34084	45687	51488	56565				
	q	1	0.746031746	0.661971831	0.602564103				
	Bulkhead	Top	1	2	3	4	5	6	
	h (m)	6.1	6.1	6.1	12.5	22.5	30	50	
	Ordinary Steel	Compt 1							
		s (mm)							
	t (mm)	4712	2945	2356	1571	1178	942	785	736
h (m)	6.1	34.330	26.073	21.567	14.878	11.533	9.527	8.189	7.771
	6.1	34.330	26.073	21.567	14.878	11.533	9.527	8.189	7.771
	6.1	34.330	26.073	21.567	14.878	11.533	9.527	8.189	7.771
	12.5	48.496	36.676	30.226	20.650	15.863	12.990	11.075	10.477
	22.5	90.503	57.502	46.502	31.834	24.501	20.101	17.167	16.251
	30	104.473	66.011	53.309	36.372	27.904	22.823	19.436	18.378
	50	134.147	84.492	68.094	46.229	35.297	28.737	24.365	22.998
	AH32								
	6.1	29.856	22.724	18.832	13.055	10.166	8.433	7.277	6.916
	6.1	29.856	22.724	18.832	13.055	10.166	8.433	7.277	6.916
	6.1	29.856	22.724	18.832	13.055	10.166	8.433	7.277	6.916
	12.5	42.092	31.882	26.311	18.041	13.906	11.424	9.770	9.253
	22.5	78.511	50.007	40.506	27.837	21.503	17.702	15.169	14.377
	30	90.577	57.356	46.385	31.757	24.443	20.054	17.128	16.214
	50	116.207	73.319	59.155	40.270	30.828	25.162	21.385	20.205
	AH36								
	6.1	28.211	21.493	17.827	12.384	9.663	8.031	6.942	6.602
	6.1	28.211	21.493	17.827	12.384	9.663	8.031	6.942	6.602
	6.1	28.211	21.493	17.827	12.384	9.663	8.031	6.942	6.602
	12.5	39.737	30.120	24.872	17.081	13.186	10.849	9.291	8.804
	22.5	74.101	47.251	38.300	26.367	20.400	16.820	14.433	13.688
	30	85.467	54.173	43.839	30.059	23.169	19.036	16.280	15.418
	50	109.610	69.210	55.868	38.079	29.184	23.847	20.289	19.178

	AH40								
	6.1	26.984	20.575	17.077	11.885	9.288	7.731	6.692	6.368
	6.1	26.984	20.575	17.077	11.885	9.288	7.731	6.692	6.368
	6.1	26.984	20.575	17.077	11.885	9.288	7.731	6.692	6.368
	12.5	37.981	28.805	23.798	16.365	12.649	10.419	8.933	8.468
	22.5	70.813	45.195	36.656	25.271	19.578	16.163	13.885	13.174
	30	81.657	51.800	41.940	28.794	22.220	18.276	15.647	14.825
	50	104.691	66.146	53.417	36.445	27.959	22.867	19.472	18.412

	Stiffener and Beams								
	f	7.8							
		Ends Att	No End Att						
	c	0.56	0.60						
		0.90	1.00						
		Compt 1	Compt 2	Compt 3	Compt 4	Compt 5	Compt 6		
	l (m)	5	5	12.5	7.5	10	10		
		Ordinary	AH32	AH36	AH40				
	Y (kg_f/mm^2)	24	32	36	40				
	U (kg_f/mm^2)	41	45	50	52				
	Q	0.972467532	0.80516129	0.72	0.668571429				
	h (m)	Top	UH Pl 0-5	UH Pl 5-10	UH Pl 10-22.5	UH Pl 22.5-32.5	UH Pl 32.5-40	MS Pl 40-50	
		6.1	6.1	6.1	6.25	17.5	26.25	35	
	Hull Plate Stiffening								
	Ordinary Steel								
		s (m)							
	SM (cm^3)	4.712	2.945	2.356	1.571	1.178	0.942	0.785	0.736
	6.1	3053	1908	1526	1018	763	611	509	477
	6.1	3053	1908	1526	1018	763	611	509	477
	6.25	19548	12217	9774	6516	4887	3910	3258	3054
	17.5	19704	12315	9852	6568	4926	3941	3284	3079
	26.25	84447	52779	42223	28149	21112	16889	14074	13195
	35	112596	70372	56298	37532	28149	22519	18766	17593
	AH32								
	6.1	2527	1580	1264	842	632	505	421	395
	6.1	2527	1580	1264	842	632	505	421	395
	6.25	16185	10115	8092	5395	4046	3237	2697	2529
	17.5	16314	10196	8157	5438	4079	3263	2719	2549
	26.25	69918	43699	34959	23306	17480	13984	11653	10925
	35	93224	58265	46612	31075	23306	18645	15537	14566
	AH36								

	6.1	2260	1413	1130	753	565	452	377	353
	6.1	2260	1413	1130	753	565	452	377	353
	6.25	14473	9046	7236	4824	3618	2895	2412	2261
	17.5	14589	9118	7294	4863	3647	2918	2431	2279
	26.25	38903	24315	19452	12968	9726	7781	6484	6079
	35	51871	32419	25935	17290	12968	10374	8645	8105
	AH40								
	6.1	2099	1312	1049	700	525	420	350	328
	6.1	2099	1312	1049	700	525	420	350	328
	6.25	13439	8399	6720	4480	3360	2688	2240	2100
	17.5	13547	8467	6773	4516	3387	2709	2258	2117
	26.25	58057	36286	29029	19352	14514	11611	9676	9071
	35	77409	48381	38705	25803	19352	15482	12902	12095
	Upper Hull Bulkhead Stiffening								
	h (m)	Top	Bkhd 1	Bkhd 2	Bkhd 3	Bkhd 4	Bkhd 5	Bkhd 6	
		6.1	6.1	6.1	12.5	22.5	30	50	
	# stiffs per bulkhead	4	8	12	16	19	20		
	spacing (m)	3.000	1.667	1.154	0.882	0.750	0.714		
	avg stiff lgth (m)	6.674	6.136	6.053	6.018	5.940	5.933		
	Ordinary Steel								
		3.000	1.667	1.154	0.882	0.750	0.714		
	6.1	3462	1626	1095	828	686	651		
	6.1	3462	1626	1095	828	686	651		
	6.1	3462	1626	1095	828	686	651		
	12.5	7095	3332	2245	1697	1405	1335		
	22.5	20525	9639	6494	4908	4065	3862		
	30	27367	12851	8658	6545	5420	5149		
	50	45612	21419	14430	10908	9033	8582		
	AH32								
	6.1	2867	1346	907	686	568	539		
	6.1	2867	1346	907	686	568	539		
	6.1	2867	1346	907	686	568	539		
	12.5	5874	2759	1859	1405	1163	1105		

	22.5	16994	7980	5376	4064	3365	3198		
	30	22659	10640	7169	5419	4487	4263		
	50	37764	17734	11948	9031	7479	7106		
	AH36								
	6.1	2564	1204	811	613	508	482		
	6.1	2564	1204	811	613	508	482		
	6.1	2564	1204	811	613	508	482		
	12.5	5253	2467	1662	1256	1040	988		
	22.5	15197	7136	4808	3634	3009	2859		
	30	20262	9515	6410	4845	4013	3813		
	50	33770	15858	10684	8076	6688	6354		
	AH40								
	6.1	2380	1118	753	569	471	448		
	6.1	2380	1118	753	569	471	448		
	6.1	2380	1118	753	569	471	448		
	12.5	4878	2291	1543	1167	966	918		
	22.5	14111	6627	4464	3375	2794	2655		
	30	18815	8835	5952	4499	3726	3540		
	50	31358	14726	9921	7499	6210	5900		

Girders and Webs		API RP-2A-WSD 21st ed 2000												
Ring Frames		Sect 3.2.5												
E (MPa, psi)	200000	29007548												
ρ_{sw} (MN/m^3, lbs/ft^3)	0.01005	64												
Hw (m, ft)	10	32.808												
k (m^{-1}, ft^{-1})	0.035816158	0.010916898												
Frame	Fr 2.5	Fr 7.5	Fr 12.5	Fr 15	Fr 17.5	Fr 20	Fr 25	Fr 27.5	Fr 30	Fr 35	Fr 37.5	Fr 42.5	Fr 45	Fr 47.5
d (m)	2	6	10	14	18									
z (m)	6	10	14	18	22									
Hz (m)	6.10	6.10	6.10	6.10	7.50	10.00	15.00	17.50	20.00	25.00	27.50	32.50	35.00	37.50
p (MN/m^2)	0.06	0.06	0.06	0.06	0.08	0.10	0.15	0.18	0.20	0.25	0.28	0.33	0.35	0.38
SF_h	1.5													
Frame Spacing (m)	2.5													
t (m)	0.005	0.01	0.015	0.02	0.025	0.03								
t/D	0.0003	0.0007	0.0010	0.0013	0.0017	0.0020								
M	12.91	9.13	7.45	6.45	5.77	5.27								
1.6D/t	4800.0	2400.0	1600.0	1200.0	960.0	800.0								
0.825D/t	2475.0	1237.5	825.0	618.8	495.0	412.5								
C_h	0.0600	0.0867	0.1080	0.1265	0.1433	0.1588								
F_{he} (MPa)	7.9953	23.1100	43.1826	67.4575	95.5068	127.0482								
	Ordinary	AH32	AH36	AH40										
F_y (MN/m^2)	235	315	355	390										
0.55F_y (MN/m^2)	129	173	195	215										
1.6F_y (MN/m^2)	376	504	568	624										
6.2F_y (MN/m^2)	1457	1953	2201	2418										
t (m)	0.005	0.01	0.015	0.02	0.025	0.03								
F_{hc} (MPa) OS	8.00	23.11	43.18	67.46	95.51	127.05								
F_{hc} (MPa) AH32	8.00	23.11	43.18	67.46	95.51	127.05								
F_{hc} (MPa) AH36	8.00	23.11	43.18	67.46	95.51	127.05								
F_{hc} (MPa) AH40	8.00	23.11	43.18	67.46	95.51	127.05								
F_{hc}/SF_h OS	5.33	15.41	28.79	44.97	63.67	84.70								
F_{hc}/SF_h AH32	5.33	15.41	28.79	44.97	63.67	84.70								
F_{hc}/SF_h AH36	5.33	15.41	28.79	44.97	63.67	84.70								
F_{hc}/SF_h AH40	5.33	15.41	28.79	44.97	63.67	84.70								
Frame	Fr 2.5	Fr 7.5	Fr 12.5	Fr 15	Fr 17.5	Fr 20	Fr 25	Fr 27.5	Fr 30	Fr 35	Fr 37.5	Fr 42.5	Fr 45	Fr 47.5
Pressure (MN/m^2)	0.06	0.061	0.061	0.061	0.075	0.101	0.151	0.176	0.201	0.251	0.276	0.327	0.352	0.377
t (m)	0.0050													
f_h (MN/m^2) OS	92	92	92	92	113	151	226	264	302	377	415	490	528	565
f_h (MN/m^2) AH32	92	92	92	92	113	151	226	264	302	377	415	490	528	565
f_h (MN/m^2) AH36	92	92	92	92	113	151	226	264	302	377	415	490	528	565
f_h (MN/m^2) AH40	92	92	92	92	113	151	226	264	302	377	415	490	528	565

t (m)	0.0100													
f_h (MN/m^2) OS	46	46	46	46	57	75	113	132	151	188	207	245	264	283
f_h (MN/m^2) AH32	46	46	46	46	57	75	113	132	151	188	207	245	264	283
f_h (MN/m^2) AH36	46	46	46	46	57	75	113	132	151	188	207	245	264	283
f_h (MN/m^2) AH40	46	46	46	46	57	75	113	132	151	188	207	245	264	283
t (m)	0.0150													
f_h (MN/m^2) OS	31	31	31	31	38	50	75	88	101	126	138	163	176	188
f_h (MN/m^2) AH32	31	31	31	31	38	50	75	88	101	126	138	163	176	188
f_h (MN/m^2) AH36	31	31	31	31	38	50	75	88	101	126	138	163	176	188
f_h (MN/m^2) AH40	31	31	31	31	38	50	75	88	101	126	138	163	176	188
t (m)	0.0200													
f_h (MN/m^2) OS	23	23	23	23	28	38	57	66	75	94	104	122	132	141
f_h (MN/m^2) AH32	23	23	23	23	28	38	57	66	75	94	104	122	132	141
f_h (MN/m^2) AH36	23	23	23	23	28	38	57	66	75	94	104	122	132	141
f_h (MN/m^2) AH40	23	23	23	23	28	38	57	66	75	94	104	122	132	141
t (m)	0.0250													
f_h (MN/m^2) OS	18	18	18	18	23	30	45	53	60	75	83	98	106	113
f_h (MN/m^2) AH32	18	18	18	18	23	30	45	53	60	75	83	98	106	113
f_h (MN/m^2) AH36	18	18	18	18	23	30	45	53	60	75	83	98	106	113
f_h (MN/m^2) AH40	18	18	18	18	23	30	45	53	60	75	83	98	106	113
t (m)	0.0300													
f_h (MN/m^2) OS	15	15	15	15	19	25	38	44	50	63	69	82	88	94
f_h (MN/m^2) AH32	15	15	15	15	19	25	38	44	50	63	69	82	88	94
f_h (MN/m^2) AH36	15	15	15	15	19	25	38	44	50	63	69	82	88	94
f_h (MN/m^2) AH40	15	15	15	15	19	25	38	44	50	63	69	82	88	94
Frame	Fr 2.5	Fr 7.5	Fr 12.5	Fr 15	Fr 17.5	Fr 20	Fr 25	Fr 27.5	Fr 30	Fr 35	Fr 37.5	Fr 42.5	Fr 45	Fr 47.5
t (m)	0.020	0.020	0.020	0.020	0.020	0.020	0.025	0.025	0.025	0.030	0.030	0.030	0.030	0.030
F_{he} (MPa)	67.46	67.46	67.46	67.46	67.46	67.46	95.51	95.51	95.51	127.05	127.05	127.05	127.05	127.05
I_c (m^4)	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0008	0.0008	0.0008	0.0013	0.0013	0.0013	0.0013	0.0013
I_c (mm^4)	474310563	474310563	474310563	474310563	474310563	474310563	839415619	839415619	839415619	1339961137	1339961137	1339961137	1339961137	1339961137
Eff Shell														
Flange Width (m)	0.6025	0.6025	0.6025	0.6025	0.6025	0.6025	0.6736	0.6736	0.6736	0.7379	0.7379	0.7379	0.7379	0.7379

MID-SECTION TRUSS						
API RP-2A-WSD 21st ed 2000						
E (MPa, psi)	200000	29007548				
ρ_{sw} (MN/m^3, lbs/ft^3)	0.01005	64				
AH36 F_y (MPa)	355					
F_t (MPa)	213					
C	0.3					
C_c	258.31					
K (§3.3.1d)	1					
C_m	0.85					
L (m)	11					
D (m)	0.5					
r (m)	xx	yy	zz			
	6.4	6.4	5.5			
KL/r	1.7	1.7	2.0			
F_a	212.67	212.67	212.62			
t (m)	0.0127	0.0254	0.0381	0.0508	0.0635	0.0762
t/D	0.0254	0.0508	0.0762	0.1016	0.1270	0.1524
D/t	39.37	19.69	13.12	9.84	7.87	6.56
F_{xe} (MPa)	3048	6096				
F_{xc} (MPa)	378	410				
$1500/F_y$	29.13					
$3000/F_y$	58					
Fb (MPa)	241	277	266	266	266	266
H_w (m, ft)	10	32.808				
k (m^{-1}, ft^{-1})	0.035816158	0.010916898				
Frame	50.5	61	70.5			

d (m)	31.3	40.2	49.1			
z (m)	31.3	40.2	49.1			
H_z (m)	40.50	51.00	60.50			
p (MN/m^2)	0.41	0.51	0.61			
SF_h	2					

Horiz Length (m)	14	Tube D (m)	0.3				Diag Length (m)	14.7		Tube D (m)	0.5		
t (m)	0.0127	0.0254	0.0381	0.0508	0.0635	0.0762	t (m)	0.0127	0.0254	0.0381	0.0508	0.0635	0.0762
t/D	0.0423	0.0847	0.1270	0.1693	0.2117	0.2540	t/D	0.0254	0.0508	0.0762	0.1016	0.1270	0.1524
D/t	23.62	11.81	7.87	5.91	4.72	3.94	D/t	39.37	19.69	13.12	9.84	7.87	6.56
M	320.76	226.81	185.19	160.38	143.45	130.95	M	260.88	184.47	150.62	130.44	116.67	106.50
1.6D/t	37.8	18.9	12.6	9.4	7.6	6.3	1.6D/t	63.0	31.5	21.0	15.7	12.6	10.5
0.825D/t	19.5	9.7	6.5	4.9	3.9	3.2	0.825D/t	32.5	16.2	10.8	8.1	6.5	5.4
C_h	0.0186	0.0373	0.0559	0.0745	0.0931	0.1118	C_h	0.0112	0.0224	0.0335	0.0447	0.0559	0.0671
F_{he} (MPa)	315.41	1261.65	2838.70	5046.58	7885.29	11354.82	F_{he} (MPa)	113.55	454.19	1021.93	1816.77	2838.70	4087.73
	AH36							AH36					
F_y (MN/m^2)	355						F_y (MN/m^2)	355					
0.55F_y (MN/m^2)	195						0.55F_y (MN/m^2)	195					
1.6F_y (MN/m^2)	568						1.6F_y (MN/m^2)	568					
6.2F_y (MN/m^2)	2201						6.2F_y (MN/m^2)	2201					
F_{hc} (MPa)	216.52	324.90	355.00	355.00	355.00	355.00	F_{hc} (MPa)	113.55	241.50	310.58	345.66	355.00	355.00
F_{hc}/SF_h	108.26	162.45	177.50	177.50	177.50	177.50	F_{hc}/SF_h	56.77	120.75	155.29	172.83	177.50	177.50
f_h (MN/m^2)							f_h (MN/m^2)						
Fr 50.5	4.8	2.4	1.6	1.2	1.0	0.8	Fr 50.5	8.0	4.0	2.7	2.0	1.6	1.3
Fr 61	6.1	3.0	2.0	1.5	1.2	1.0	Fr 61	10.1	5.0	3.4	2.5	2.0	1.7
Fr 70.5	7.2	3.6	2.4	1.8	1.4	1.2	Fr 70.5	12.0	6.0	4.0	3.0	2.4	2.0

LOWER HULL			LH OD (mm)		15000			
					Compt 10	Compt 11	Compt 12	
			LH Compt Ht (mm)		5000	5000	9500	
Plate								
Stiffs per panel	10	16	20	30	40	50	60	64
Radial Spacing (mm)	4712.39	2945.24	2356.19	1570.80	1178.10	942.48	785.40	736.31
α								
Compt 10	1.061	1.698	2.122	3.183	4.244	5.305	6.366	6.791
Compt 11	1.061	1.698	2.122	3.183	4.244	5.305	6.366	6.791
Compt 12	2.016	3.226	4.032	6.048	8.064	10.080	12.096	12.902
k								
Compt 10	0.818	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Compt 11	0.818	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Compt 12	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

	Hull Structural Steel							
		Higher Strength						
	Ordinary	AH32	AH36	AH40				
Y (N/mm^2)	235	315	355	390				
Y (psi)	34084	45687	51488	56565				
q	1	0.746031746	0.661971831	0.602564103				
Bulkhead	7	8	9	10				
h (m)	60.5	70	75	80				
Ordinary Steel	Compt 1							
	s (mm)							
t (mm)	4712	2945	2356	1571	1178	942	785	736
60.5	120.545	92.691	74.653	50.602	38.577	31.361	26.551	25.048
70	129.476	99.514	80.112	54.241	41.306	33.545	28.371	26.754
75	133.932	102.920	82.836	56.057	42.668	34.634	29.279	27.605
80	138.243	106.213	85.470	57.814	43.985	35.688	30.157	28.428
AH32								
60.5	104.460	80.401	64.821	44.047	33.660	27.428	23.274	21.975
70	112.173	86.294	69.536	47.190	36.018	29.314	24.845	23.449
75	116.022	89.235	71.888	48.759	37.194	30.255	25.629	24.184
80	119.745	92.080	74.164	50.276	38.332	31.166	26.388	24.895
AH36								
60.5	98.544	75.881	61.205	41.637	31.852	25.982	22.068	20.845
70	105.810	81.433	65.646	44.597	34.073	27.758	23.549	22.233
75	109.436	84.203	67.862	46.075	35.181	28.645	24.287	22.926
80	112.943	86.882	70.006	47.504	36.253	29.502	25.002	23.596
AH40								
60.5	94.133	72.511	58.509	39.839	30.504	24.904	21.170	20.003
70	101.065	77.807	62.746	42.664	32.623	26.598	22.582	21.327
75	75	75	75	75	75	75	75	75
80	80	80	80	80	80	80	80	80

Stiffener and Beams								
f	7.8							
	Ends Att	No End Att						
c	0.90	1.00						
	Compt 10	Compt 11	Compt 12					
l (m)	5	5	9.5					
	Ordinary	AH32	AH36	AH40				
Y (kg_f/mm^2)	24	32	36	40				
U (kg_f/mm^2)	41	45	50	52				
Q	0.972467532	0.80516129	0.72	0.668571429				
h (m)	LH Pl 80-85	LH Pl 85-90	LH Pl 70.5-80					
	72.5	77.5	65					
Hull Plate Stiffening								
Ordinary Steel								
	s (m)							
SM (cm^3)	4.712	2.945	2.356	1.571	1.178	0.942	0.785	0.736
72.5	58308	36443	29154	19436	14577	11662	9718	9111
77.5	62330	38956	31165	20777	15582	12466	10388	9739
65	188718	117949	94359	62906	47180	37744	31453	29487
AH32								
72.5	48277	30173	24138	16092	12069	9655	8046	7543
77.5	51606	32254	25803	17202	12902	10321	8601	8063
65	156251	97657	78125	52084	39063	31250	26042	24414
AH36								
72.5	43171	26982	21585	14390	10793	8634	7195	6745
77.5	46148	28842	23074	15383	11537	9230	7691	7211
65	139724	87328	69862	46575	34931	27945	23287	21832
AH40								
72.5	40087	25054	20044	13362	10022	8017	6681	6264
77.5	42852	26782	21426	14284	10713	8570	7142	6696
65	129744	81090	64872	43248	32436	25949	21624	20272

Lower Hull Bulkhead Stiffening								
h (m)	Bkhd 7	Bkhd 8	Bkhd 9	Bkhd 10				
	60.5	70	75	80				
# stiffs per bulkhead	4	8	12	16	19	20		
spacing (m)	3.000	1.667	1.154	0.882	0.750	0.714		
avg stiff lgth (m)	6.674	6.136	6.053	6.018	5.940	5.933		
Ordinary Steel								
	3.000	1.667	1.154	0.882	0.750	0.714		
60.5	55190	25917	17461	13198	10930	10385		
70	63856	29987	20202	15271	12646	12015		
75	68417	32129	21645	16361	13549	12873		
80	72979	34271	23088	17452	14452	13732		
AH32								
60.5	45695	21458	14457	10928	9049	8598		
70	52870	24828	16727	12643	10470	9948		
75	56647	26601	17921	13547	11218	10659		
80	60423	28375	19116	14450	11966	11369		
AH36								
60.5	40862	19189	12927	9772	8092	7689		
70	47278	22202	14957	11306	9363	8896		
75	50655	23788	16026	12114	10031	9531		
80	54032	25373	17094	12921	10700	10167		
AH40								
60.5	37943	17818	12004	9074	7514	7139		
70	43901	20616	13889	10499	8694	8260		
75	47037	22088	14881	11248	9315	8850		
80	50173	23561	15873	11998	9936	9441		

Girders and Webs		API RP-2A-WSD 21st ed 2000				
Ring Frames		Sect 3.2.5				
E (MPa, psi)	200000	29007548				
ρ_{sw} (MN/m^3, lbs/ft^3)	0.01005	64				
Hw (m, ft)	10	32.808				
k (m^{-1}, ft^{-1})	0.035816158	0.010916898				
Frame	Fr 73	Fr 75.5	Fr 82.5	Fr 84		
d (m)	2	6	10	14	18	
z (m)	6	10	14	18	22	
Hz (m)	63.00	65.50	72.50	73.00		
p (MN/m^2)	0.63	0.66	0.73	0.73		
SF_h	1.5					
Frame Spacing (m)	2					
t (m)	0.03	0.035	0.04	0.045	0.05	0.055
t/D	0.0020	0.0023	0.0027	0.0030	0.0033	0.0037
M	4.22	3.90	3.65	3.44	3.27	3.11
1.6D/t	800.0	685.7	600.0	533.3	480.0	436.4
0.825D/t	412.5	353.6	309.4	275.0	247.5	225.0
C_h	0.2056	0.2252	0.2441	0.2618	0.2789	0.2955
F_{he} (MPa)	164.4523	210.2256	260.3452	314.1849	371.8773	433.3993
	Ordinary	AH32	AH36	AH40		
F_y (MN/m^2)	235	315	355	390		
$0.55F_y$ (MN/m^2)	129	173	195	215		
$1.6F_y$ (MN/m^2)	376	504	568	624		
$6.2F_y$ (MN/m^2)	1457	1953	2201	2418		
t (m)	0.030	0.035	0.040	0.045	0.050	0.055
F_{hc} (MPa) OS	135.35	143.59	152.61	162.30	172.69	181.92
F_{hc} (MPa) AH32	164.45	179.59	188.61	198.30	208.69	219.76

F_{hc} (MPa) AH36	164.45	197.59	206.61	216.30	226.69	237.76
F_{hc} (MPa) AH40	164.45	210.23	222.36	232.05	242.44	253.51
F_{hc}/SF_h OS	90.23	95.73	101.74	108.20	115.13	121.28
F_{hc}/SF_h AH32	109.63	119.73	125.74	132.20	139.13	146.51
F_{hc}/SF_h AH36	109.63	131.73	137.74	144.20	151.13	158.51
F_{hc}/SF_h AH40	109.63	140.15	148.24	154.70	161.63	169.01
Frame	Fr 73	Fr 75.5	Fr 82.5	Fr 84		
Pressure (MN/m^2)	0.633	0.658	0.729	0.734		
t (m)	0.0300					
f_h (MN/m^2) OS	158	165	182	183		
f_h (MN/m^2) AH32	158	165	182	183		
f_h (MN/m^2) AH36	158	165	182	183		
f_h (MN/m^2) AH40	158	165	182	183		
t (m)	0.0350					
f_h (MN/m^2) OS	136	141	156	157		
f_h (MN/m^2) AH32	136	141	156	157		
f_h (MN/m^2) AH36	136	141	156	157		
f_h (MN/m^2) AH40	136	141	156	157		
t (m)	0.0400					
f_h (MN/m^2) OS	119	123	137	138		
f_h (MN/m^2) AH32	119	123	137	138		
f_h (MN/m^2) AH36	119	123	137	138		
f_h (MN/m^2) AH40	119	123	137	138		

t (m)	0.0450					
f_h (MN/m^2) OS	106	110	121	122		
f_h (MN/m^2) AH32	106	110	121	122		
f_h (MN/m^2) AH36	106	110	121	122		
f_h (MN/m^2) AH40	106	110	121	122		
t (m)	0.0500					
f_h (MN/m^2) OS	95	99	109	110		
f_h (MN/m^2) AH32	95	99	109	110		
f_h (MN/m^2) AH36	95	99	109	110		
f_h (MN/m^2) AH40	95	99	109	110		
t (m)	0.0550					
f_h (MN/m^2) OS	86	90	99	100		
f_h (MN/m^2) AH32	86	90	99	100		
f_h (MN/m^2) AH36	86	90	99	100		
f_h (MN/m^2) AH40	86	90	99	100		
Frame	Fr 73	Fr 75.5	Fr 82.5	Fr 84		
t (m)	0.045	0.045	0.045	0.045		
F_{he} (MPa)	314.18	314.18	314.18	314.18		
I_c (m^4)	0.0040	0.0040	0.0040	0.0040		
I_c (mm^4)	3976403201	3976403201	3976403201	3976403201		
Eff Shell						
Flange Width (m)	0.9037	0.9037	0.9037	0.9037		

Factor of Safety			1.15				
				AH36			
Upper Hull				t (mm)	w FoS		
	Shell Plating						
		Fr 0-10		6.6	7.6		
		Fr 10-40		15.4	17.7		
		Fr 40-50		19.2	22.1		
		CL Tube 0-10		6.6	7.6		
		CL Tube 10-40		15.4	17.7		
	Bulkhead Plating						
		Top		6.6	7.6		
		Bkhd 1		6.6	7.6		
		Bkhd 2		6.6	7.6		
		Bkhd 3		8.8	10.1		
		Bkhd 4		13.7	15.7		
		Bkhd 5		15.4	17.7		
		Bkhd 6		19.2	22.1		
		Long 0-10		6.6	7.6		
		Long 10-40		15.4	17.7		
		Trans 0-10		6.6	7.6		
		Trans 10-40		15.4	17.7		
		Trans 40-50		19.2	22.1		
				I_c (mm^4)			
	Girder						
		Fr 2.5		474310563	545457147	474	
		Fr 7.5		474310563	545457147	474	
		Fr 12.5		474310563	545457147	474	
		Fr 15		474310563	545457147	474	
		Fr 17.5		474310563	545457147	474	
		Fr 20		474310563	545457147	474	
		Fr 25		839415619	965327961	839	
		Fr 27.5		839415619	965327961	839	
		Fr 30		839415619	965327961	839	
		Fr 35		1339961137	1540955308	1340	
		Fr 37.5		1339961137	1540955308	1340	
		Fr 42.5		1339961137	1540955308	1340	
		Fr 45		1339961137	1540955308	1340	
		Fr 47.5		1339961137	1540955308	1340	
	Stiffeners			SM (cm^3)			
		Plate				Bulb Flat	
			Fr 0-5	353	406	160 x 11.5	
			Fr 5-10	353	406	160 x 11.5	
			Fr 10-22.5	2261	2601	240 x 11	
			Fr 22.5-32.5	2279	2621	240 x 11	
			Fr 32.5-40	6079	6990	240 x 11	
			Fr 40-50	8105	9321	370 x 16	
		Bulkhead					
			Top	508	584	160 x 11.5	
			B 1	508	584	160 x 11.5	
			B 2	508	584	160 x 11.5	
			B 3	1040	1196	240 x 11	
			B 4	3009	3461	240 x 11	
			B 5	4013	4614	320 x 11.5	
			B 6	6688	7691	370x12.5	

			100				Piece	A (mm^2)	y (m)	Ay (mm^3)	Ay^2 (mm^4)	I_o (mm^4)	
20			1				1	2000	345	690000	238050000	66667	
							2	6700	167.5	1122250	187976875	62658958	
							3	7230	6	43380	260280	86760	
			2					15930		1855630	426287155	62812385	
				335									
							Ring Frame				y (mm)	116	
							Fr 2.5-20				I_{yy} (mm^4)	489099540	489
			20								SM (cm^3)	4199	
12			3										
			602.5										
			100				Piece	A (mm^2)	y (m)	Ay (mm^3)	Ay^2 (mm^4)	I_o (mm^4)	
25			1				1	2500	392.5	981250	385140625	130208	
							2	9500	190	1805000	342950000	114316667	
							3	11451	8.5	97335	827349	275783	
			2					23451		2883585	728917974	114722658	
				380									
							Ring Frame				y (mm)	123	
							Fr 25-30				I_{yy} (mm^4)	843640632	844
			25								SM (cm^3)	6861	
17			3										
			673.6										
			100				Piece	A (mm^2)	y (m)	Ay (mm^3)	Ay^2 (mm^4)	I_o (mm^4)	
30			1				1	3000	445	1335000	594075000	225000	
							2	12900	215	2773500	596302500	198767500	
							3	12544	8.5	106627	906326	302109	
			2					28444		4215127	1191283826	199294609	
				430									
							Ring Frame				y (mm)	148	
							Fr 35-47.5				I_{yy} (mm^4)	1390578434	1391
			30								SM (cm^3)	9384	
17			3										
			737.9										

				AH36	
Middle Section					
	Truss			OD (mm)	t (mm)
		Verticals		1000.0	38.1
		Horizontals		300.0	12.7
		Diagonals		500.0	12.7

				AH36			
Lower Hull				t (mm)	w FoS		
	Shell Plating						
		Fr 70.5-80		22.23	26		
		Fr 80-85		22.93	26		
		Fr 85-90		23.60	27		
	Bulkhead						
		B 7		20.85	24		
		B 8		22.23	26		
		B 9		22.93	26		
		B 10		23.60	27		
		Transverse					
			Fr 70.5-80	23.60			
	Stiffeners			SM (cm^3)			
		Plate					
			Fr 70.5-80	6745	7757	370 x 12.5	
			Fr 80-85	7211	8292	370 x 13	
			Fr 85-90	21832	25107	430x20	
		Bulkhead					
			B 7	7689	8842	370 x 15	
			B 8	8896	10230	400 x 13	
			B 9	9531	10961	400 x 14	
			B 10	10167	11692	400 x 15	
		Transverse					
			Fr 70.5-80	21832	25107	430x20	
	Ring Frame			I_c (mm^4)			
			Fr 73	3976403201		3976	
			Fr 75.5	3976403201		3976	
			Fr 82.5	3976403201		3976	
			Fr 84	3976403201		3976	

Remora Iteration 2.1

Structural Scantlings Summary

Upper Hull					t (mm)		
	Shell Plating						
		Fr 0-10			12		
		Fr 10-40			18		
		Fr 40-50			20		
		CL Tube 0-10			12		
		CL Tube 10-40			18		
	Bulkhead Plating						
		Top			12		
		Bkhd 1			12		
		Bkhd 2			12		
		Bkhd 3			18		
		Bkhd 4			18		
		Bkhd 5			18		
		Bkhd 6			20		
		Long 0-10			12		
		Long 10-40			18		
		Trans 0-10			12		
		Trans 10-40			18		
		Trans 40-50			20		
	Stiffeners			SM (cm^3)	Bulb Flat (mm)	CS Area (mm^2)	
		Shell					
			Fr 0-5	406	160 x 8	1620	
			Fr 5-10	406	160 x 8	1620	
			Fr 10-22.5	2601	260 x 11	3870	
			Fr 22.5-30	2621	260 x 11	3870	
			Fr 30-40	6990	340 x 12	5880	
			Fr 40-50	9321	370 x 13	6960	
		Bulkhead					
			Top	584	180 x 8	1890	
			B 1	584	180 x 8	1890	
			B 2	584	180 x 8	1890	
			B 3	1196	220 x 9	2680	
			B 4	3461	280 x 12	4550	
			B 5	4614	300 x 13	5280	
			B 6	7691	370 x 13	6900	
					T Bar (mm)		
		Girder		I_c (mm^4)	flange x web x t	CS Area (mm^2)	
			Fr 2.5	474310563	100 x 335 x 20	15930	320
			Fr 7.5	474310563	100 x 335 x 20	15930	320
			Fr 12.5	474310563	100 x 335 x 20	15930	520
			Fr 15	474310563	100 x 335 x 20	15930	520

			Fr 17.5	474310563	100 x 335 x 20	15930	520
			Fr 20	474310563	100 x 335 x 20	15930	520
			Fr 25	839415619	100 x 380 x 25	23451	520
			Fr 27.5	839415619	100 x 380 x 25	23451	520
			Fr 32.5	839415619	100 x 380 x 25	23451	680
			Fr 35	1339961137	100 x 430 x 30	28444	680
			Fr 37.5	1339961137	100 x 430 x 30	28444	680
			Fr 42.5	1339961137	100 x 430 x 30	28444	740
			Fr 45	1339961137	100 x 430 x 30	28444	740
			Fr 47.5	1339961137	100 x 430 x 30	28444	740

	Qty	Lgth (mm)	OD (mm)	t (mm)	Area (mm^2)	Vol (mm^3)	Wt (kg)
Upper Hull							
Hull Plate							
Fr 0-10	1	10000	15000	12.000	565034	5650342883	45212
Fr 0-10 Tube	1	10000	2500	12.000	93795	937953903	7505
Fr 10-40	1	30000	15000	18.000	847212	25416364213	203372
Fr 10-40 Tube	1	30000	2500	18.000	140354	4210613802	33692
Fr 40-50	0.1	10000	15000	20.000	470611	4706105795	3766
Longitudinal Stiffeners							
Fr 0-10	1	10000			1620	16200000	130
Fr 10-30	1	20000			3870	77400000	619
Fr 30-40	1	10000			5880	58800000	470
Fr 40-50	1	10000			6960	69600000	557
Bulkheads							
Top	1		15000	12.000	171805848	2061670179	16497
B 1	1		15000	12.000	171805848	2061670179	16497
B 2	1		15000	12.000	171805848	2061670179	16497
B 3	1		15000	18.00	171805848	3092505268	24745
B 4	1		15000	18.00	171805848	3092505268	24745
B 5	1		15000	18.00	171805848	3092505268	24745
B 6	0.25		15000	20.00	171805848	3436116965	6874
Longitudinal							
Fr 0-10	1	10000	6250	12.00	62500000	750000000	6001
Fr 10-40	1	30000	6250	18.00	187500000	3375000000	27005
Transverse							
Fr 0-10	1	10000	6250	12.00	62500000	750000000	6001
Fr 10-40	1	30000	6250	18.00	187500000	3375000000	27005
Fr 40-50	1	10000	15000	20.00	150000000	3000000000	24005
Diagonals							
Fr 0-10	0.25	10000	6250	12.00	62500000	750000000	1500
Fr 10-40	0.25	30000	6250	18.00	187500000	3375000000	6751
Bulkhead Stiffeners							
Top	1	11880			1890	22453200	180
B 1	1	11880			1890	22453200	180
B 2	1	11880			1890	22453200	180
B 3	1	11880			2680	31838400	255
B 4	1	11880			4550	54054000	433
B 5	1	11880			5280	62726400	502
B 6	0.5	5940			6900	40986000	164
Longitudinal							
Fr 0-10	1	10000			1620	16200000	130
Fr 10-40	1	30000			5880	176400000	1411
Transverse							
Fr 0-10	1	10000			1620	16200000	130
Fr 10-40	1	30000			5880	176400000	1411
Diagonals							
Fr 0-10	0.5	10000			1890	18900000	76
Fr 10-40	0.5	30000			3870	116100000	464
Ring Frames							
Fr 2.5	1	47124	15000		15930	750683565	6007
Fr 7.5	1	47124	15000		15930	750683565	6007
Fr 12.5	1	47124	15000		15930	750683565	6007
Fr 15	1	47124	15000		15930	750683565	6007
Fr 17.5	1	47124	15000		15930	750683565	6007
Fr 20	1	47124	15000		15930	750683565	6007

Fr 25	1	47124	15000	23451	1105102340	8843
Fr 27.5	1	47124	15000	23451	1105102340	8843
Fr 32.5	1	47124	15000	23451	1105102340	8843
Fr 35	1	47124	15000	28444	1340391922	10725
Fr 37.5	1	47124	15000	28444	1340391922	10725
Fr 42.5	1	38562	15000	28444	1096855961	8777
Fr 45	1	38562	15000	28444	1096855961	8777
Fr 47.5	1	38562	15000	28444	1096855961	8777

				AH36	
Middle Section					
	Truss			OD (mm)	t (mm)
		Verticals		1000.0	38.1
		Horizontals		300.0	12.7
		Diagonals		500.0	12.7

	Qty	Lgth (mm)	OD (mm)	t (mm)	Area (mm^2)	Vol (mm^3)	Wt (kg)
Mid-Section							
Vertical Tubes							
Compt 6	1	10000	1000	38.1	115134	1151343128	9213
Compt 7	1	10000	1000	38.1	115134	1151343128	9213
Compt 8	1	10000	1000	38.1	115134	1151343128	9213
Compt 9	1	10000	1000	38.1	115134	1151343128	9213
Horizontal Tubes							
Compt 6	1	9600	300	12.7	11463	110042501	881
Compt 7	1	9600	300	12.7	11463	110042501	881
Compt 8	1	9600	300	12.7	11463	110042501	881
Braces							
Compt 6	1	14760	500	12.7	19442	286969911	2296
Compt 7	1	14760	500	12.7	19442	286969911	2296
Compt 8	1	14760	500	12.7	19442	286969911	2296
Compt 9	1	14760	500	12.7	19442	286969911	2296

Lower Hull					t (mm)		
	Shell Plating						
		Fr 70.5-80			24		
		Fr 80-85			24		
		Fr 85-90			24		
	Bulkhead						
		B 7			24		
		B 8			24		
		B 9			24		
		B 10			24		
		Transverse					
			Fr 70.5-80		24		
	Stiffeners			SM (cm^3)	Bulb Flat (mm)	CS Area (mm^2)	
		Plate					
			Fr 70.5-80	25107	430 x 20	11500	
			Fr 80-85	7757	340 x 15	6900	
			Fr 85-90	8292	370 x 12.5	6780	
		Bulkhead					
			B 7	8842	370 x 12.5	6780	
			B 8	10230	370 x x15	7700	
			B 9	10961	370 x 16	8070	
			B 10	11692	400 x 13	7740	
		Longitudinal					
			Fr 80-85	7757	340 x 15	6900	
			Fr 85-90	8292	370 x 12.5	6780	
		Transverse					
			Fr 70.5-80	25107	430 x 20	11500	
			Fr 80-85	7757	340 x 15	6900	
			Fr 85-90	8292	370 x 12.5	6780	
					T Bar (mm)		
	Ring Frame			I_c (mm^4)	flange x web x t	CS Area (mm^2)	
			Fr 72.5	3976403201	100 x 550 x 45	52204	860
			Fr 75	3976403201	100 x 550 x 45	52204	860
			Fr 77.5		100 x 550 x 45		860
			Fr 82.5	3976403201	100 x 550 x 45	52204	680
			Fr 85	3976403201	100 x 550 x 45	52204	740

	Qty	Lgth (mm)	OD (mm)	t (mm)	Area (mm^2)	Vol (mm^3)	Wt (kg)
Lower Hull							
Hull Plate							
Fr 70.5-80	1	9500	15000	24.000	376388	3575685360	28611
Fr 70.5-80 Trans	1	9500	13000	24.000	123500000	2964000000	23717
Fr 80-85	1	5000	15000	24.000	1129164	5645818990	45176
Fr 85-90	1	5000	15000	24.000	1129164	5645818990	45176
Longitudinal Stiffeners							
Fr 70.5-80	1	9500			11500.0	109250000	874
Fr 70.5-80 Trans	1	9500			11500.0	109250000	874
Fr 80-85	1	5000			6900	34500000	276
Fr 85-90	1	5000			6780	33900000	271
Bulkheads							
B 7	1		15000	24.000	34543611	829046664	6634
B 8	1		15000	24.000	176714587	4241150082	33936
B 9	1		15000	24.000	176714587	4241150082	33936
B10	1		15000	24.000	176714587	4241150082	33936
Longitudinal							
Fr 80-85	1	5000	15000	24.00	75000000	1800000000	14403
Fr 85-90	1	5000	15000	24.00	75000000	1800000000	14403
Transverse							
Fr 80-85	1	5000	15000	24.00	75000000	1800000000	14403
Fr 85-90	1	5000	15000	24.00	75000000	1800000000	14403
Bulkhead Stiffeners							
B 7	1	1875			11500.0	21562500	173
B 8	1	6164			7700.0	47462800	380
B 9	1	6164			8070.0	49743480	398
B10	1	6164			7740.0	47709360	382
Longitudinal							
Fr 80-85	1	5000			6900.0	34500000	276
Fr 85-90	1	5000			6780.0	33900000	271
Transverse							
Fr 80-85	1	5000			6900.0	34500000	276
Fr 85-90	1	5000			6780.0	33900000	271
Ring Frames							
Fr 73	1	28708	15000		52204	1498670514	11992
Fr 75.5	1	28708	15000		52204	1498670514	11992
Fr 82.5	1	47124	15000		52204	2460055543	19684
Fr 84	1	47124	15000		52204	2460055543	19684

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-25
FEA Truss
OTEC-2010-001

17 September 2010

Prepared for:

Naval Facilities Engineering Command
Naval Facilities Engineering Service Center (NFESC)
1100 23rd Avenue
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Attn: Mr. Brian Cable, Contracting Officer Representative

Prepared by:

Lockheed Martin MS2
9500 Godwin Drive
Manassas, VA 20110

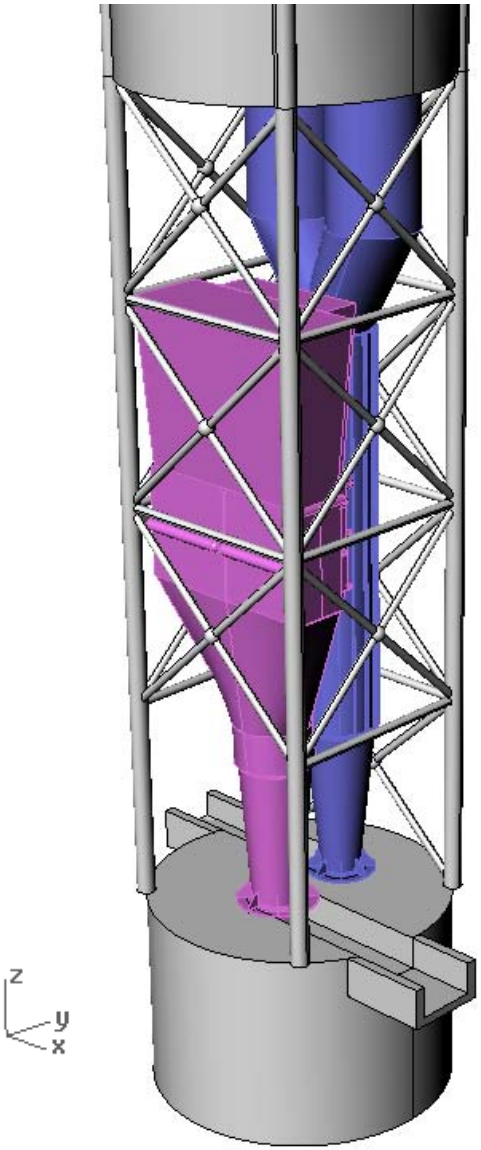
Distribution Statement A: Approved for public release; distribution is unlimited

APPENDIX 3.3.2.1.1-14

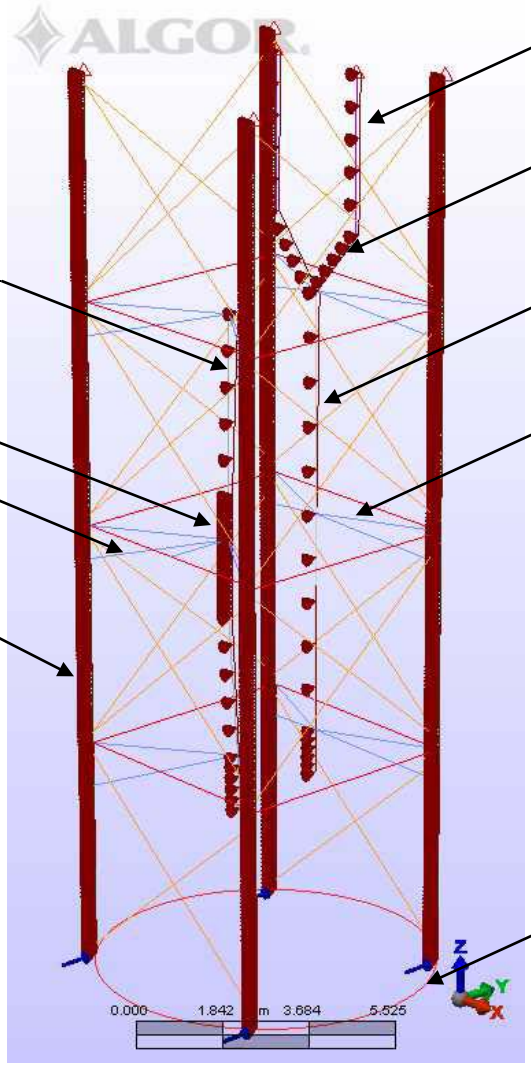
Remora Iteration 2.1—Finite Element Analysis for Truss

Remora Truss Model Setup

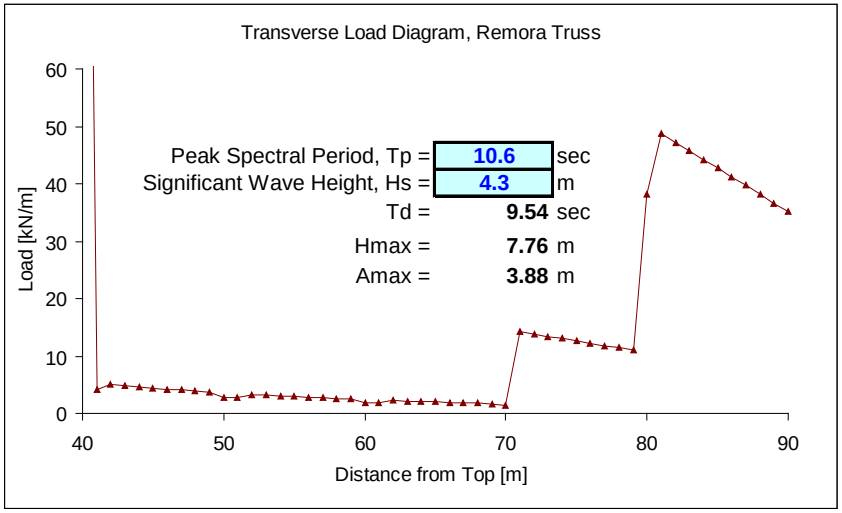
Design

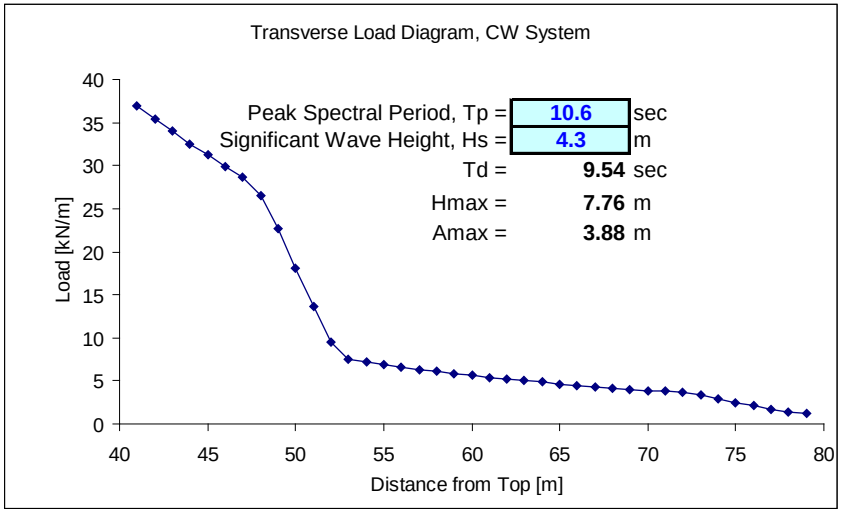


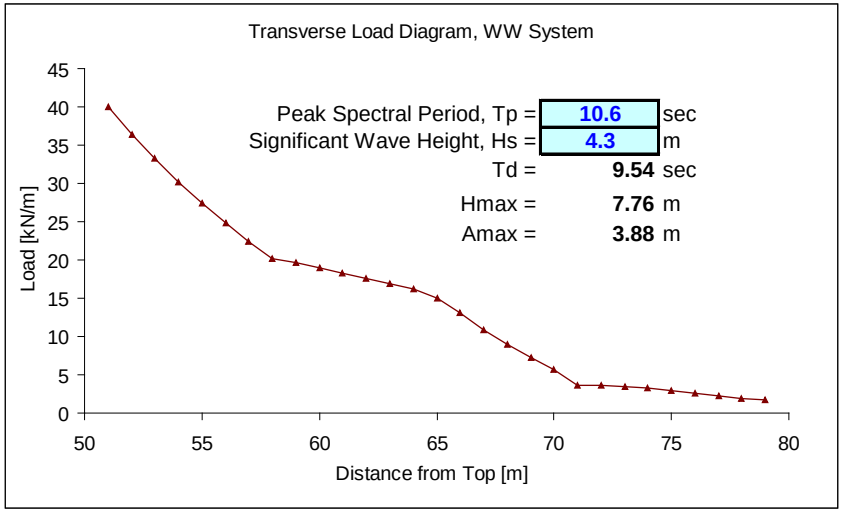
Model



Truss, CW, WW Load Inputs





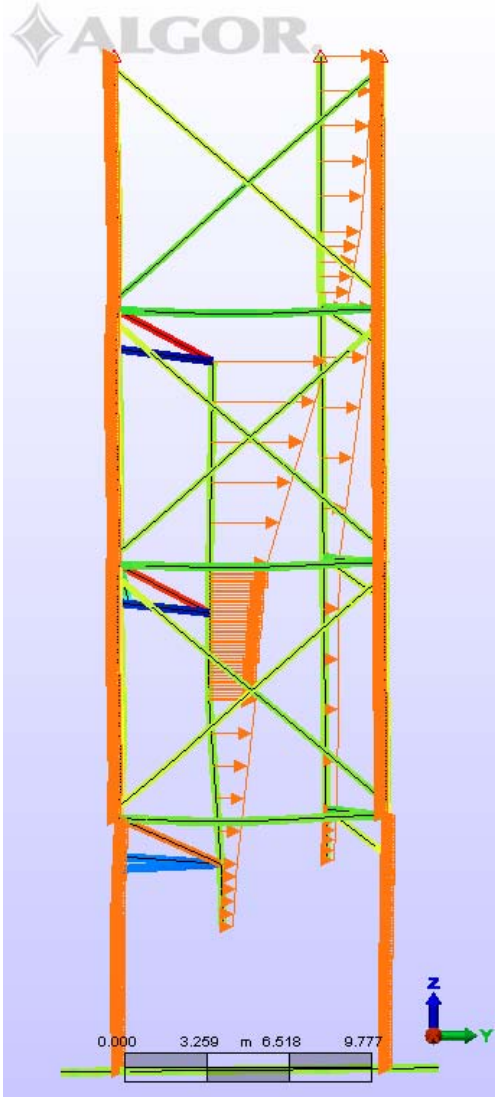


Weights - Totals

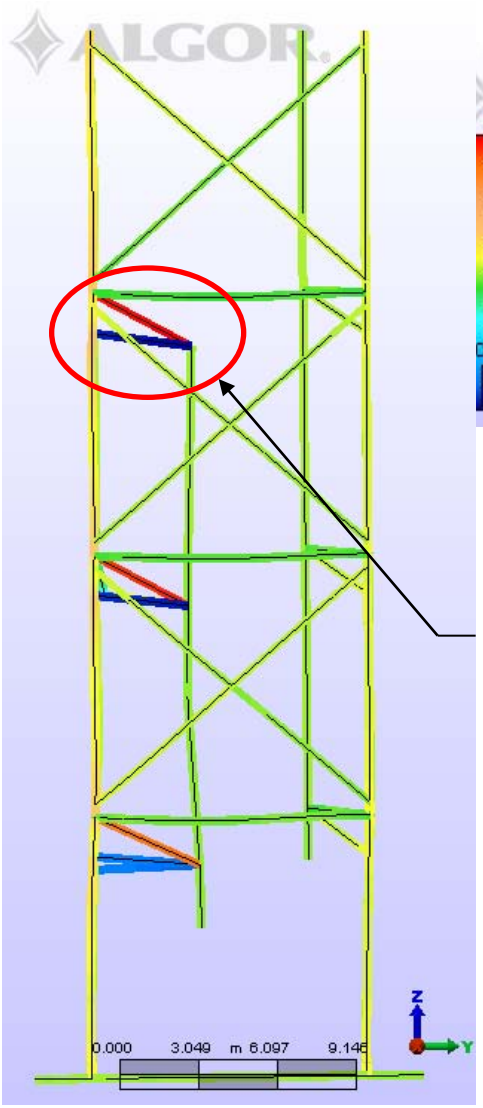
	Dry Weights [kg] WW	Dry Weights [kg] CW	Displacement [kg] WW	Displacement [kg] CW	Wet Weight [kg] WW	Wet Weight [kg] CW	Totals [N]	
Intake =	49582		6466		**43116**			
Hx =	336300	200000	126641	125035	**209659**	**74965**	660123	WW duct
Converger =		17090		2229		**14861**	**2056757**	WW Hx
Ductwork =		36283		4732		**31551**	455309	CW duct
Converger =	27800		3625		**24175**		**735411**	CW Hx
Pump =	50000	40000	6520	5216	**43480**	**34784**		
Soft Tank =	676550		88227		**588323**		6539213	Soft Tank

Remora Truss Worst Stress

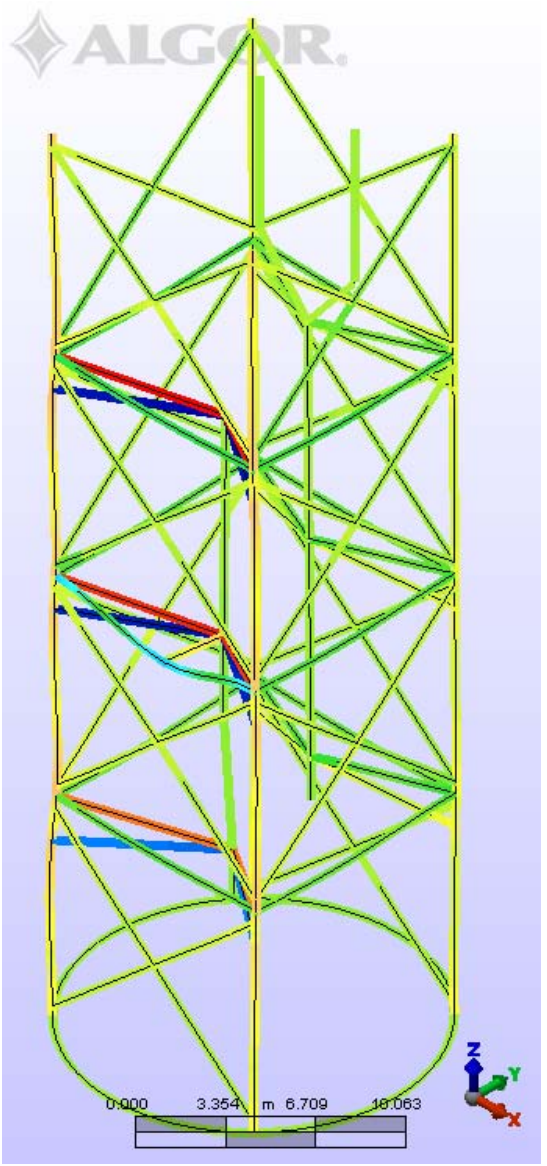
With Loads



Without Loads

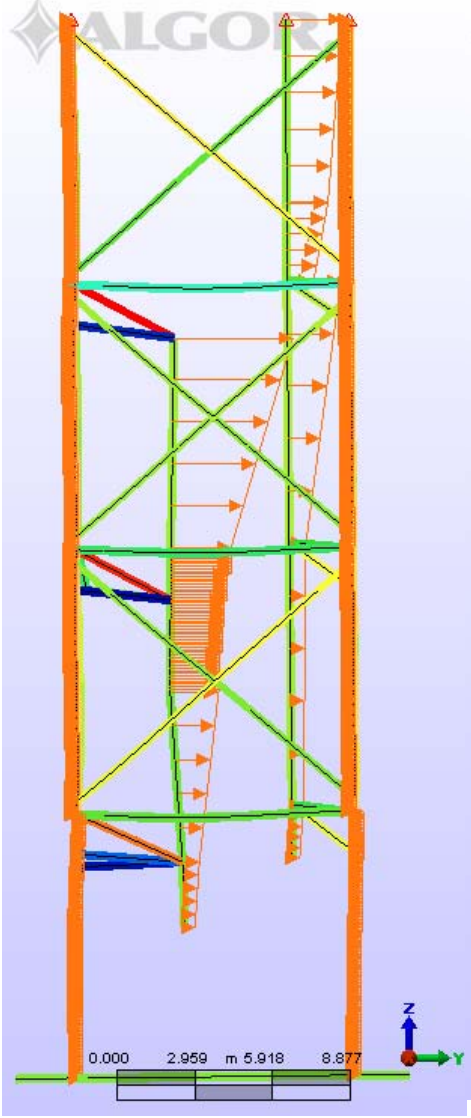


Foundation design critical

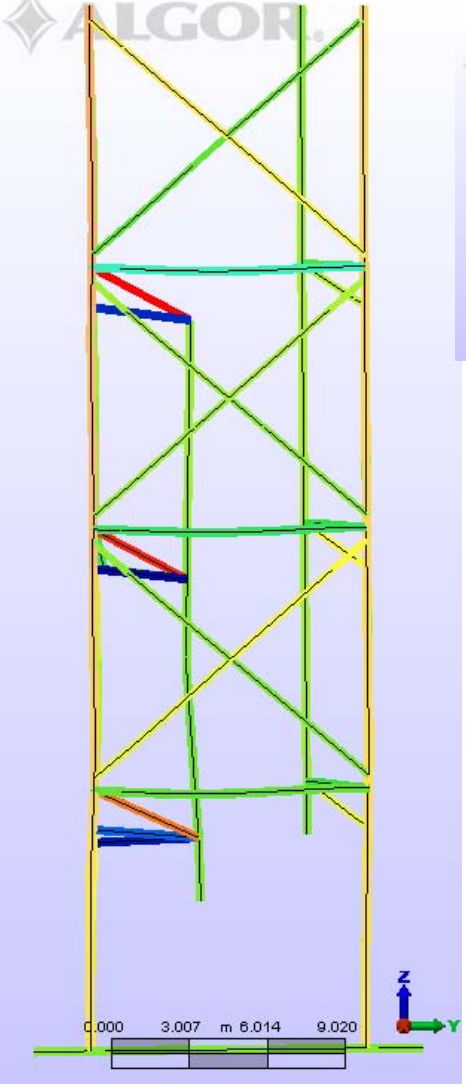


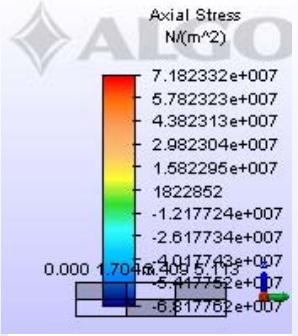
Remora Truss Axial Stress

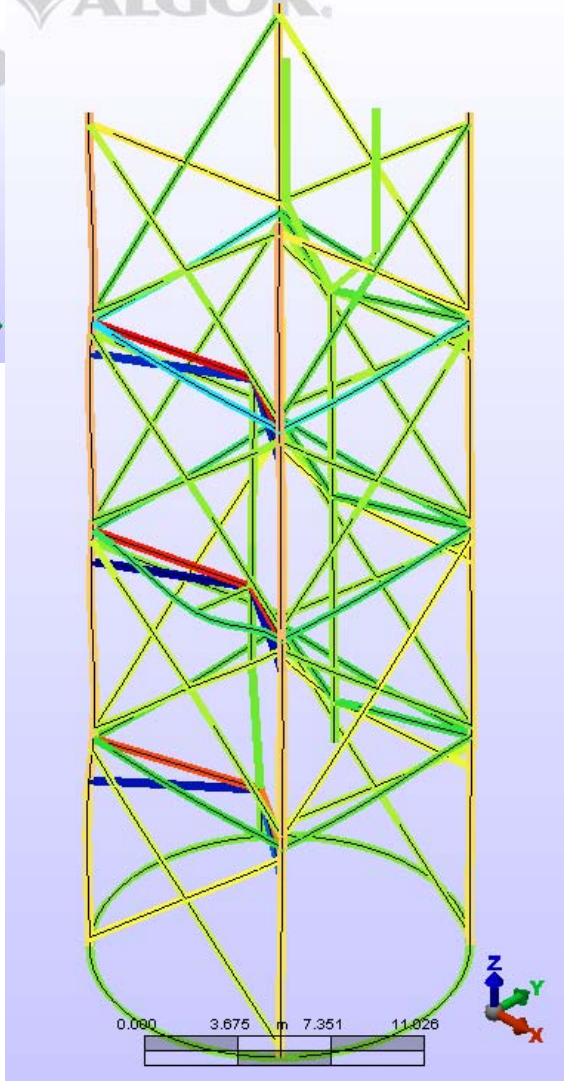
With Loads



Without Loads

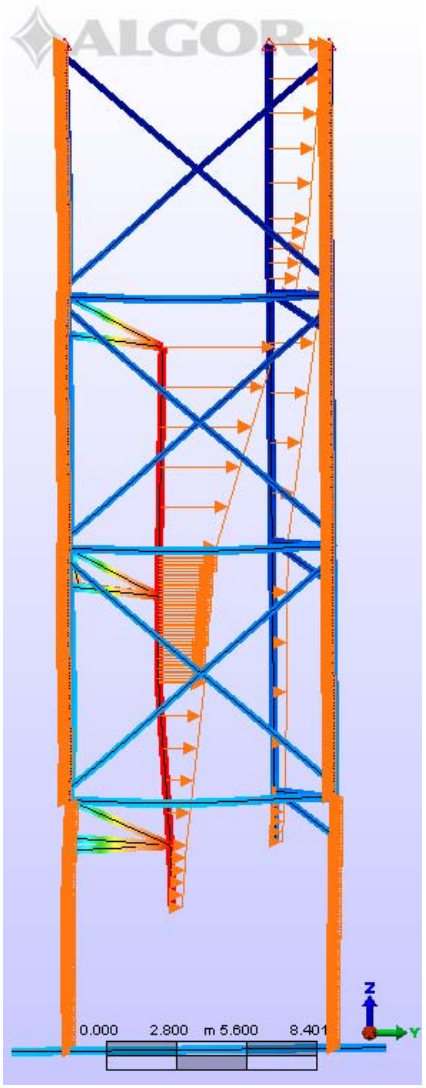




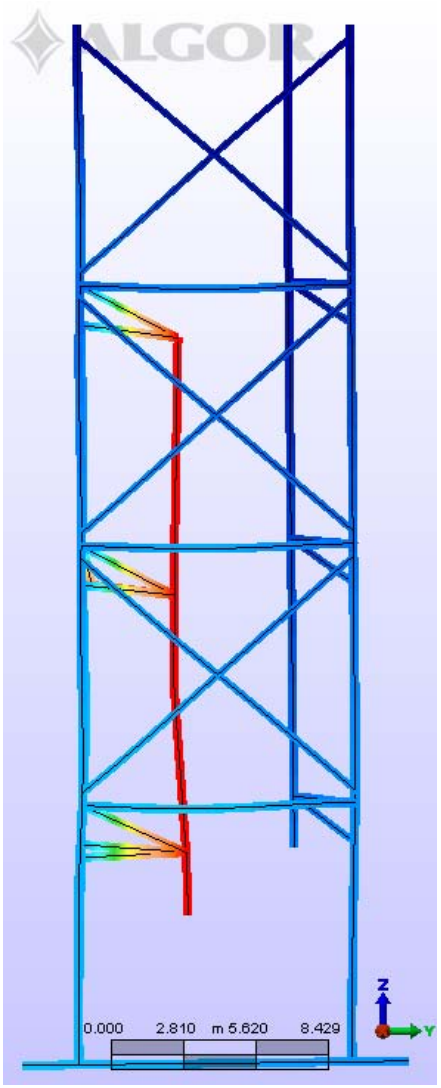


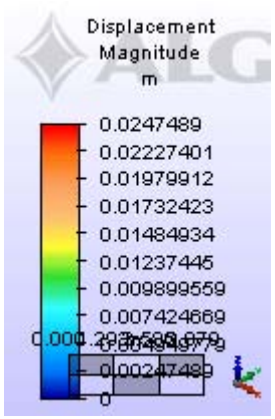
Remora Truss Displacements

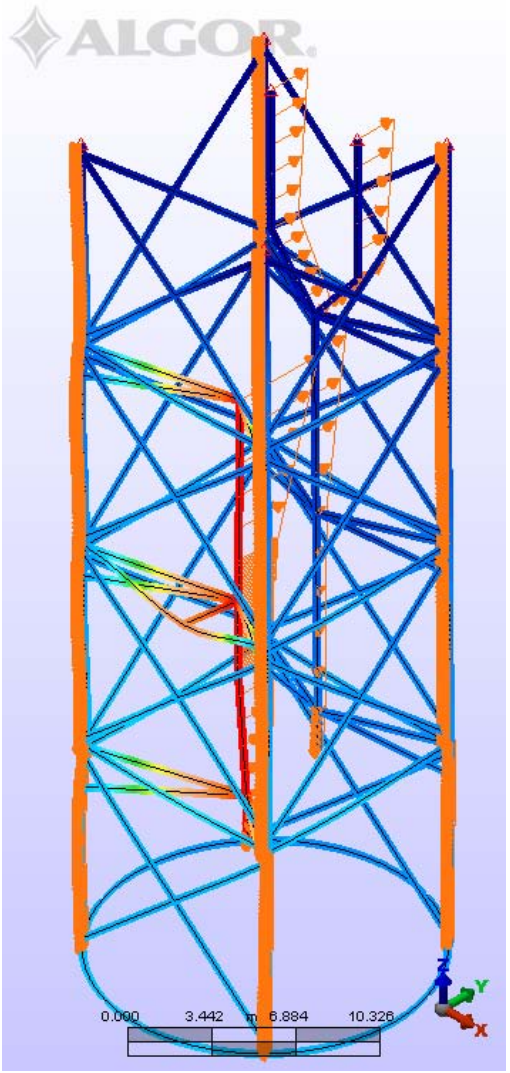
With Loads



Without Loads







Mass Properties Output

Model Information

Volume (m^3)	1.66E+02	Weight (N)	1.28E+07		
Center of Gravity (m)	Mass Moment of Intertia (	Mass Product of Intertia ($N*s^2*m$)			
Xc (m)	-4.05E-05	Ixx ($N*s^2*m$)	1.36E+09	Ixy ($N*s^2*m$	1.82E+02
Yc (m)	-1.67E-01	Iyy ($N*s^2*m$)	1.35E+09	Ixz ($N*s^2*m$	2.31E+03
Zc (m)	-2.93E+01	Izz ($N*s^2*m$)	5.14E+07	Iyz ($N*s^2*m$	8.69E+06

Part Information

Part	Volume (m^3)		Mass [kg]	Weight (N)	Xc (m)	Yc (m)	Zc (m)	Ixx ($N*s^2*m$)	Iyy ($N*s^2*m$)	Izz ($N*s^2*m$)	Ixy ($N*s^2*m$)	Ixz ($N*s^2*m$)	Iyz ($N*s^2*m$)
2 < Horizontals >		1.46E+00	11465	112470	0	0	-20	5562800	5562800	429690	0	0	0
3 < Verticals >		1.84E+01	144404	1416600	0	0	-20	81038000	81038000	8118000	0	0	0
4 < Diagonals >		7.57E+00	59508	583770	0	0	-18	26875000	26716000	2230200	0	0	0
5 < Cross-Lumped Masses >		2.94E+00	23076	226380	0	0	-20	11528000	11381000	569930	182	2310	-12728
6 < Soft Tank >		8.48E+01	666269	6536100	0	0	-40	1084200000	1084200000	37396000	0	0	0
7 < CW System >		5.91E+00	46477	455940	0	3	-18	17781000	17416000	416050	0	0	-2387900
8 < WW Duct >		8.74E+00	68700	673950	0	-2	-21	35522000	35272000	250480	0	0	2716700
9 < CW Hx >		9.55E+00	75019	735940	0	3	-4	1855400	1693400	1099300	0	0	-761090
10 < WW Hx >		2.67E+01	209664	2056800	0	-2	-21	91684000	90760000	924190	0	0	9131900

Soft Tank includes Pump weights

Weight Inputs

Weights - Totals								
	Dry Weights [kg]		Displacement [kg]		Wet Weight [kg]		Totals [N]	
	WW	CW	WW	CW	WW	CW		
Intake =	49582		6466		43116			
Hx =	336300	200000	126641	125035	209659	74965	660123	WW duct
Converger =		17090		2229		14861	2056757	WW Hx
Ductwork =		36283		4732		31551	455309	CW duct
Converger =	27800		3625		24175		735411	CW Hx
Pump =	50000	40000	6520	5216	43480	34784		
Soft Tank =	676550		88227		588323		6539213	Soft Tank

Good Correlation

Beam Properties

		Beam Element Properties					
Part No.	Description	A	J1	I2	I3	S2	S3
1	Hardtank						
2	Horizontals	0.011463	0.000237	0.000118	0.000118	0.000790	0.000790
3	Verticals	0.114844	0.026612	0.013306	0.013306	0.026612	0.026612
4	Diagonals	0.019442	0.001155	0.000577	0.000577	0.002310	0.002310
5	CW/WW Foundations	0.019442	0.001155	0.000577	0.000577	0.002310	0.002310
6	Soft Tank (with pumps)	1.799937	1.284311	0.642156	0.642156	0.642156	0.642156
7	CW Duct	0.198394	0.927954	0.463977	0.463977	0.213814	0.213814
8	WW Duct	0.513575	2.376395	1.188197	1.188197	0.547556	0.547556
9	CW Hx	0.681863	3.136826	1.568413	1.568413	0.722771	0.722771
10	WW Hx	4.850804	19.096989	9.548494	9.548494	4.400228	4.400228

Notes

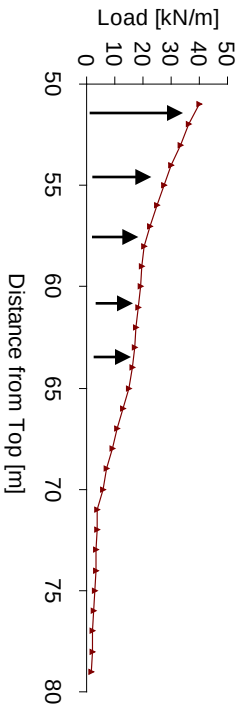
Cheat Sheet:

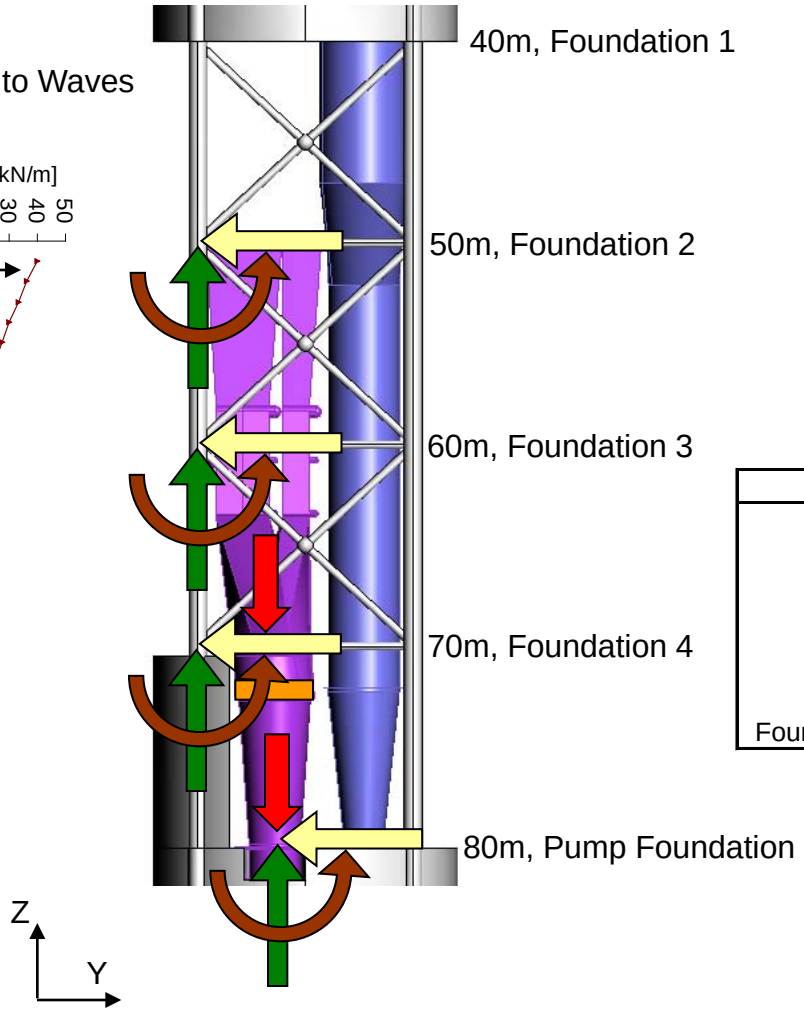
1MPa = 10^6 N/m^2

Yield Strength, Steel A36 = 250 MPa = $2.5x10^8$ N/m^2

WW System Loads

Inertial Load due to Waves
25 Year Cyclone





Weight

	Wet Weight [kg-f]	
	WW	CW
Intake =	40357	0
Hx =	117160	122150
Converger =	0	10940
Ductwork =	0	27058
Converger =	23188	0
Pump =	43030	33338
Total =	223735	193486

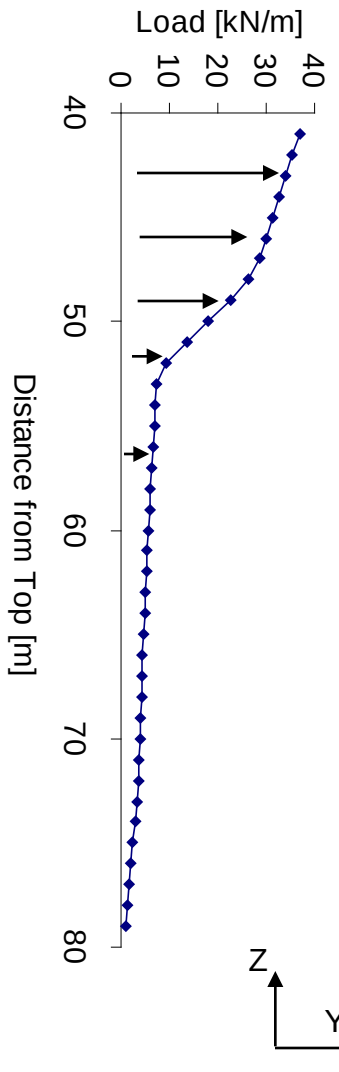
$F = (m + m_A)^* (g + a) + Drag$ (Drag → 0)
Added Mass, m_A = 25% of Mass
Acceleration, a = 0.1g

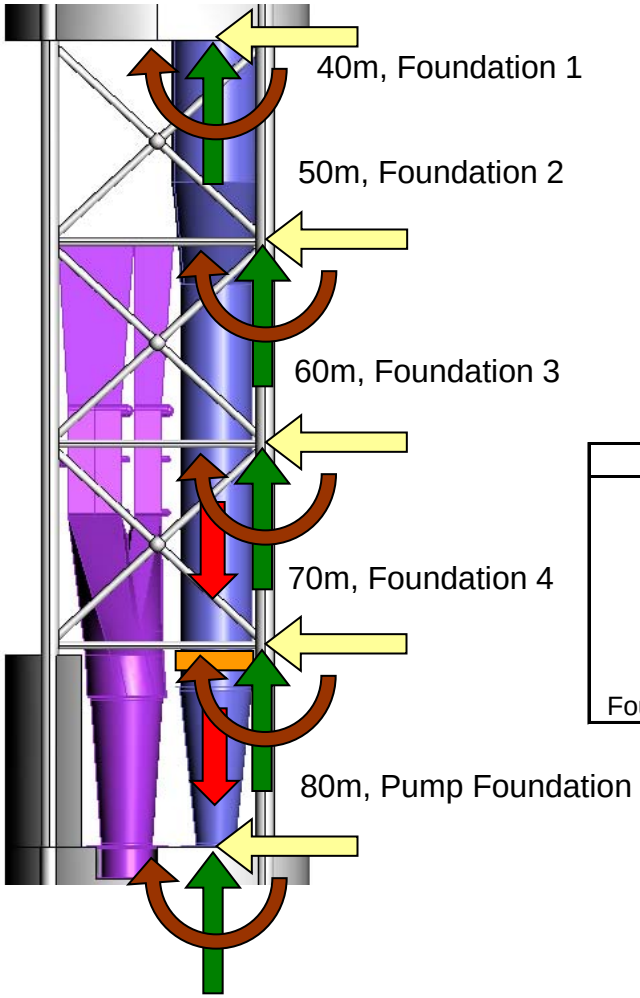
CW/WW Reactions			
	Transverse [kN]	Vertical [kN]	Moment [kN-m]
	WW	WW	WW
Foundation 1 =			
Foundation 2 =	167	389	807
Foundation 3 =	190	1805	2764
Foundation 4 =	53	243	473
Foundation, Pump =	18	580	84

Bellows (Assumption: Won't transfer any load)

CW System Loads

Inertial Load due to Waves
25 Year Cyclone





Weight

Wet Weight [kg-f]	WW	CW
Intake =	40357	0
Hx =	117160	122150
Converger =	0	10940
Ductwork =	0	27058
Converger =	23188	0
Pump =	43030	33338
Total =	**223735**	**193486**

$F = (m + m_A)^* (g + a) + Drag$ → 0

Added Mass, m_A = 25% of Mass

Acceleration, a = 0.1g

CW/WW Reactions	Transverse [kN]	Vertical [kN]	Moment [kN-m]
	CW	CW	CW
Foundation 1 =	170	1177	425
Foundation 2 =	171	676	2907
Foundation 3 =	56	192	782
Foundation 4 =	25	115	512
Foundation, Pump =	19	450	101

Bellows (Assumption: Won't transfer any load)

H:\OTEC REMORA-

Design Analysis

OTEC Pilot Plant Remora

Created by

Author: Steve Schmitz
Department: Navatek Engineering
Created Date: 5/25/2010

Reviewed by

Reviewer: Dick Holcomb
Department: Engineering
Model Created Date: 5/25/2010
Reviewer Comments:

Executive Summary

This report documents some initial results on the truss for the NAVFAC OTEC Pilot Plant to be located 7 miles south of Barbers Point on the island of Oahu. The focus of this analysis is the structural response of the truss due the inertial loads of the truss itself and the loads imparted onto the truss from the cold water (CW) and warm water (WW) systems during a 25 year cyclone event.

Loads imparted onto the model, as distributed loads in the Y-direction, where calculated from load RAOs normalized to the wave period Tp, significant wave height Hs, the cross sectional area and length. The wave used for this analysis is a 25 year cyclone wave. An acceleration of 0.1g was used in the vertical (Z-direction) and an acceleration of 0.02g's in the transverse Y-direction.

The model was constructed using beam elements throughout. For the non-critical structural areas for this analysis, such as the WW and CW systems, beam properties were used such that the mass is as predicted in the weight statement. Polar moments of inertia and moments of inertia were calculated accordingly.

In summary the truss, as designed, is capable of surviving a 25 year cyclone storm. The area that requires close attention are the WW system foundations. The WW foundations, as modeled in this current analysis, yield under

its own weight and wave loads.

A detailed analysis of the WW foundations will need to be investigated.

Summary

Model Information

Analysis Type - Static Stress with Linear Material Models
Units - Metric mks (SI) - (N, m, s, deg C, deg C, V, ohm, A, J)
Model location - H:\OTEC Remora-2010\Loads & Structures\Algor\Truss\Remora Truss-Beam Elements with CW_WW.fem
Design scenario description - Design Scenario # 1

Analysis Parameters Information

Load Case Multipliers

Static Stress with Linear Material Models may have multiple load cases. This allows a model to be analyzed with multiple loads while solving the equations a single time. The following is a list of load case multipliers that were analyzed with this model.

Load Case	Pressure/Surface Forces	Acceleration/Gravity	Rotation	Angular Acceleration	Displaced Boundary	Thermal	Voltage
1	1	1	0	0	0		

Gravity Information

The following lists the values used if acceleration or gravity was included in the analysis. The Acceleration/Gravity direction multiplier is multiplied by the Acceleration Due To Body Force which is then multiplied by the Acceleration/Gravity load case multiplier.
Acceleration Due To Body Force = 9.81456 m/s²

Acceleration/Gravity X Multiplier	Acceleration/Gravity Y Multiplier	Acceleration/Gravity Z Multiplier
0	0.02	-1.1

Multiphysics Information

Default Nodal Temperature	0 °C
Source of Initial Nodal Temperatures	None
Time step from Heat Transfer	Last

Analysis	

Processor Information

Type of Solver	Automatic
Disable Calculation and Output of Strains	No
Calculate Reaction Forces	Yes
Invoke Banded Solver	Yes
Avoid Bandwidth Minimization	No
Stop After Stiffness Calculations	No
Displacement Data in Output File	No
Stress Data in Output File	No
Equation Numbers Data in Output File	No
Element Input Data in Output File	No
Nodal Input Data in Output File	No
Centrifugal Load Data in Output File	No

Part Information

Part ID	Part Name	Element Type	Material Name
2	Horizontals	Beam	Steel (ASTM - A36)
3	Verticals	Beam	Steel (ASTM - A36)
4	Diagonals	Beam	Steel (ASTM - A36)
5	CW/WW Foundations	Beam	Steel (ASTM - A36)
6	Soft Tank	Beam	Steel (ASTM - A36)
7	CW Duct	Beam	Steel (ASTM - A36)
8	WW Duct	Beam	Steel (ASTM - A36)
9	CW Hx	Beam	Steel (ASTM - A36)
10	WW Hx	Beam	Steel (ASTM - A36)

Element Information

Element Properties used for:

- Horizontals

Element Type	Beam
Stress Free Reference Temperature	0 °C
Layer 1 - Area	0.011463
Layer 1 - SA2	0
Layer 1 - SA3	0
Layer 1 - J1	0.000237
Layer 1 - I2	0.000118
Layer 1 - I3	0.000118
Layer 1 - S2	0.00079
Layer 1 - S3	0.00079

Element Properties used for:

- Verticals

Element Type	Beam
Stress Free Reference Temperature	0 °C
Layer 1 - Area	0.114844
Layer 1 - SA2	0
Layer 1 - SA3	0
Layer 1 - J1	0.026612
Layer 1 - I2	0.013306
Layer 1 - I3	0.013306
Layer 1 - S2	0.026612
Layer 1 - S3	0.026612

Element Properties used for:

- Diagonals

Element Type	Beam
Stress Free Reference Temperature	0 °C
Layer 1 - Area	0.019442
Layer 1 - SA2	0
Layer 1 - SA3	0
Layer 1 - J1	0.001155
Layer 1 - I2	0.000577
Layer 1 - I3	0.000577
Layer 1 - S2	0.00231
Layer 1 - S3	0.00231

Element Properties used for:

- CW/WW Foundations

Element Type	Beam
Stress Free Reference Temperature	0 °C
Layer 1 - Area	0.019442
Layer 1 - SA2	0
Layer 1 - SA3	0
Layer 1 - J1	0.001155
Layer 1 - I2	0.000577
Layer 1 - I3	0.000577
Layer 1 - S2	0.00231
Layer 1 - S3	0.00231

Element Properties used for:

- Soft Tank

Element Type	Beam
Stress Free Reference Temperature	0 °C
Layer 1 - Area	1.79994
Layer 1 - SA2	0
Layer 1 - SA3	0
Layer 1 - J1	1.28431
Layer 1 - I2	0.642156
Layer 1 - I3	0.642156
Layer 1 - S2	0.642156
Layer 1 - S3	0.642156

Element Properties used for:

- CW Duct

Element Type	Beam
Stress Free Reference Temperature	0 °C
Layer 1 - Area	0.198394
Layer 1 - SA2	0
Layer 1 - SA3	0
Layer 1 - J1	0.927954
Layer 1 - I2	0.463977
Layer 1 - I3	0.463977
Layer 1 - S2	0.213814

Layer 1 - S3	0.213814

Element Properties used for:

- WW Duct

Element Type	Beam
Stress Free Reference Temperature	0 °C
Layer 1 - Area	0.513575
Layer 1 - SA2	0
Layer 1 - SA3	0
Layer 1 - J1	2.3764
Layer 1 - I2	1.1882
Layer 1 - I3	1.1882
Layer 1 - S2	0.547556
Layer 1 - S3	0.547556

Element Properties used for:

- CW Hx

Element Type	Beam
Stress Free Reference Temperature	0 °C
Layer 1 - Area	0.681863
Layer 1 - SA2	0
Layer 1 - SA3	0
Layer 1 - J1	3.13683
Layer 1 - I2	1.56841
Layer 1 - I3	1.56841
Layer 1 - S2	0.722771
Layer 1 - S3	0.722771

Element Properties used for:

- WW Hx

Element Type	Beam
Stress Free Reference Temperature	0 °C
Layer 1 - Area	4.8508
Layer 1 - SA2	0
Layer 1 - SA3	0
Layer 1 - J1	19.097
Layer 1 - I2	9.54849
Layer 1 - I3	9.54849
Layer 1 - S2	4.40023
Layer 1 - S3	4.40023

Material Information

Steel (ASTM - A36) -Beam

Material Model	Standard
Material Source	Algor Material Library
Material Source File	C:\Program Files\ALGOR\22.01\matlibs\algormat.mlb
Date Last Updated	2004/09/30-16:00:00
Material Description	Structural Steel
Mass Density	7855 kg/m³
Modulus of Elasticity	199950000000 N/m²
Poisson's Ratio	0.29
Thermal Coefficient of Expansion	0.0000117 1/°C

Loads

FEA Object Group 15: Beam Distributed Loads

Beam Distributed Load

ID	Description	Line ID	Element ID	Magnitude-I	Vx-I	Vy-I	Vz-I	Magnitude-J	Vx-J	Vy-J	Vz-J	A	B
101	Unnamed	6	1	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
102	Unnamed	7	2	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
103	Unnamed	8	3	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
104	Unnamed	9	4	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
105	Unnamed	10	5	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
106	Unnamed	11	6	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
107	Unnamed	12	7	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
108	Unnamed	13	8	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
109	Unnamed	14	9	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
110	Unnamed	15	10	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
111	Unnamed	16	11	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
112	Unnamed	17	12	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
113	Unnamed	18	13	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
114	Unnamed	19	14	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
115	Unnamed	20	15	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
116	Unnamed	21	16	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
117	Unnamed	22	17	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
118	Unnamed	23	18	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
119	Unnamed	24	19	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
120	Unnamed	25	20	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
121	Unnamed	86	81	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
122	Unnamed	87	82	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
123	Unnamed	88	83	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
124	Unnamed	89	84	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
125	Unnamed	90	85	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
126	Unnamed	91	86	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
127	Unnamed	92	87	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000

128	Unnamed	93	88	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
129	Unnamed	94	89	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
130	Unnamed	95	90	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
131	Unnamed	96	91	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
132	Unnamed	97	92	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
133	Unnamed	98	93	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
134	Unnamed	99	94	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
135	Unnamed	100	95	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
136	Unnamed	101	96	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
137	Unnamed	102	97	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
138	Unnamed	103	98	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
139	Unnamed	104	99	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
140	Unnamed	105	100	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
141	Unnamed	166	161	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
142	Unnamed	167	162	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
143	Unnamed	168	163	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
144	Unnamed	169	164	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
145	Unnamed	170	165	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
146	Unnamed	171	166	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
147	Unnamed	172	167	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
148	Unnamed	173	168	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
149	Unnamed	174	169	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
150	Unnamed	175	170	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
151	Unnamed	176	171	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
152	Unnamed	177	172	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
153	Unnamed	178	173	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
154	Unnamed	179	174	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
155	Unnamed	180	175	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
156	Unnamed	181	176	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
157	Unnamed	182	177	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
158	Unnamed	183	178	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
159	Unnamed	184	179	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
160	Unnamed	185	180	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
161	Unnamed	246	241	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000

162	Unnamed	247	242	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
163	Unnamed	248	243	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
164	Unnamed	249	244	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
165	Unnamed	250	245	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
166	Unnamed	251	246	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
167	Unnamed	252	247	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
168	Unnamed	253	248	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
169	Unnamed	254	249	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
170	Unnamed	255	250	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
171	Unnamed	256	251	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
172	Unnamed	257	252	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
173	Unnamed	258	253	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
174	Unnamed	259	254	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
175	Unnamed	260	255	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
176	Unnamed	261	256	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
177	Unnamed	262	257	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
178	Unnamed	263	258	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
179	Unnamed	264	259	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
180	Unnamed	265	260	1000.000000	0.000000	1.000000	0.000000	1000.000000	0.000000	1.000000	0.000000	0.000000	1.000000

FEA Object Group 16: Beam Distributed Loads

Beam Distributed Load

ID	Description	Line ID	Element ID	Magnitude-I	Vx-I	Vy-I	Vz-I	Magnitude-J	Vx-J	Vy-J	Vz-J	A	B
181	Unnamed	26	21	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
182	Unnamed	27	22	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
183	Unnamed	28	23	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
184	Unnamed	29	24	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
185	Unnamed	30	25	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
186	Unnamed	31	26	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
187	Unnamed	32	27	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
188	Unnamed	33	28	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
189	Unnamed	34	29	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
190	Unnamed	35	30	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000

191	Unnamed	36	31	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
192	Unnamed	37	32	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
193	Unnamed	38	33	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
194	Unnamed	39	34	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
195	Unnamed	40	35	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
196	Unnamed	41	36	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
197	Unnamed	42	37	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
198	Unnamed	43	38	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
199	Unnamed	44	39	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
200	Unnamed	45	40	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
201	Unnamed	106	101	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
202	Unnamed	107	102	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
203	Unnamed	108	103	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
204	Unnamed	109	104	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
205	Unnamed	110	105	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
206	Unnamed	111	106	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
207	Unnamed	112	107	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
208	Unnamed	113	108	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
209	Unnamed	114	109	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
210	Unnamed	115	110	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
211	Unnamed	116	111	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
212	Unnamed	117	112	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
213	Unnamed	118	113	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
214	Unnamed	119	114	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
215	Unnamed	120	115	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
216	Unnamed	121	116	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
217	Unnamed	122	117	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
218	Unnamed	123	118	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
219	Unnamed	124	119	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
220	Unnamed	125	120	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
221	Unnamed	186	181	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
222	Unnamed	187	182	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
223	Unnamed	188	183	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
224	Unnamed	189	184	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000

225	Unnamed	190	185	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
226	Unnamed	191	186	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
227	Unnamed	192	187	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
228	Unnamed	193	188	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
229	Unnamed	194	189	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
230	Unnamed	195	190	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
231	Unnamed	196	191	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
232	Unnamed	197	192	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
233	Unnamed	198	193	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
234	Unnamed	199	194	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
235	Unnamed	200	195	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
236	Unnamed	201	196	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
237	Unnamed	202	197	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
238	Unnamed	203	198	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
239	Unnamed	204	199	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
240	Unnamed	205	200	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
241	Unnamed	266	261	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
242	Unnamed	267	262	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
243	Unnamed	268	263	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
244	Unnamed	269	264	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
245	Unnamed	270	265	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
246	Unnamed	271	266	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
247	Unnamed	272	267	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
248	Unnamed	273	268	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
249	Unnamed	274	269	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
250	Unnamed	275	270	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
251	Unnamed	276	271	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
252	Unnamed	277	272	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
253	Unnamed	278	273	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
254	Unnamed	279	274	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
255	Unnamed	280	275	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
256	Unnamed	281	276	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
257	Unnamed	282	277	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
258	Unnamed	283	278	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000

259	Unnamed	284	279	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000
260	Unnamed	285	280	700.000000	0.000000	1.000000	0.000000	700.000000	0.000000	1.000000	0.000000	0.000000	1.000000

FEA Object Group 17: Beam Distributed Loads

Beam Distributed Load

ID	Description	Line ID	Element ID	Magnitude-I	Vx-I	Vy-I	Vz-I	Magnitude-J	Vx-J	Vy-J	Vz-J	A	B
261	Unnamed	46	41	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
262	Unnamed	47	42	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
263	Unnamed	48	43	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
264	Unnamed	49	44	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
265	Unnamed	50	45	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
266	Unnamed	51	46	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
267	Unnamed	52	47	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
268	Unnamed	53	48	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
269	Unnamed	54	49	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
270	Unnamed	55	50	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
271	Unnamed	56	51	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
272	Unnamed	57	52	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
273	Unnamed	58	53	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
274	Unnamed	59	54	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
275	Unnamed	60	55	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
276	Unnamed	61	56	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
277	Unnamed	62	57	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
278	Unnamed	63	58	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
279	Unnamed	64	59	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
280	Unnamed	65	60	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
281	Unnamed	126	121	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
282	Unnamed	127	122	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
283	Unnamed	128	123	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
284	Unnamed	129	124	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
285	Unnamed	130	125	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
286	Unnamed	131	126	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
287	Unnamed	132	127	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000

288	Unnamed	133	128	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
289	Unnamed	134	129	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
290	Unnamed	135	130	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
291	Unnamed	136	131	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
292	Unnamed	137	132	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
293	Unnamed	138	133	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
294	Unnamed	139	134	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
295	Unnamed	140	135	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
296	Unnamed	141	136	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
297	Unnamed	142	137	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
298	Unnamed	143	138	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
299	Unnamed	144	139	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
300	Unnamed	145	140	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
301	Unnamed	206	201	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
302	Unnamed	207	202	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
303	Unnamed	208	203	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
304	Unnamed	209	204	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
305	Unnamed	210	205	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
306	Unnamed	211	206	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
307	Unnamed	212	207	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
308	Unnamed	213	208	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
309	Unnamed	214	209	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
310	Unnamed	215	210	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
311	Unnamed	216	211	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
312	Unnamed	217	212	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
313	Unnamed	218	213	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
314	Unnamed	219	214	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
315	Unnamed	220	215	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
316	Unnamed	221	216	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
317	Unnamed	222	217	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
318	Unnamed	223	218	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
319	Unnamed	224	219	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
320	Unnamed	225	220	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
321	Unnamed	286	281	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000

322	Unnamed	287	282	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
323	Unnamed	288	283	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
324	Unnamed	289	284	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
325	Unnamed	290	285	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
326	Unnamed	291	286	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
327	Unnamed	292	287	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
328	Unnamed	293	288	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
329	Unnamed	294	289	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
330	Unnamed	295	290	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
331	Unnamed	296	291	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
332	Unnamed	297	292	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
333	Unnamed	298	293	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
334	Unnamed	299	294	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
335	Unnamed	300	295	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
336	Unnamed	301	296	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
337	Unnamed	302	297	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
338	Unnamed	303	298	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
339	Unnamed	304	299	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
340	Unnamed	305	300	500.000000	0.000000	1.000000	0.000000	500.000000	0.000000	1.000000	0.000000	0.000000	1.000000

FEA Object Group 18: Beam Distributed Loads

Beam Distributed Load

ID	Description	Line ID	Element ID	Magnitude-I	Vx-I	Vy-I	Vz-I	Magnitude-J	Vx-J	Vy-J	Vz-J	A	B
341	Unnamed	66	61	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
342	Unnamed	67	62	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
343	Unnamed	68	63	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
344	Unnamed	69	64	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
345	Unnamed	70	65	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
346	Unnamed	71	66	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
347	Unnamed	72	67	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
348	Unnamed	73	68	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
349	Unnamed	74	69	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
350	Unnamed	75	70	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000

351	Unnamed	76	71	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
352	Unnamed	77	72	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
353	Unnamed	78	73	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
354	Unnamed	79	74	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
355	Unnamed	80	75	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
356	Unnamed	81	76	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
357	Unnamed	82	77	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
358	Unnamed	83	78	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
359	Unnamed	84	79	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
360	Unnamed	85	80	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
361	Unnamed	146	141	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
362	Unnamed	147	142	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
363	Unnamed	148	143	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
364	Unnamed	149	144	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
365	Unnamed	150	145	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
366	Unnamed	151	146	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
367	Unnamed	152	147	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
368	Unnamed	153	148	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
369	Unnamed	154	149	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
370	Unnamed	155	150	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
371	Unnamed	156	151	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
372	Unnamed	157	152	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
373	Unnamed	158	153	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
374	Unnamed	159	154	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
375	Unnamed	160	155	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
376	Unnamed	161	156	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
377	Unnamed	162	157	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
378	Unnamed	163	158	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
379	Unnamed	164	159	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
380	Unnamed	165	160	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
381	Unnamed	226	221	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
382	Unnamed	227	222	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
383	Unnamed	228	223	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
384	Unnamed	229	224	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000

385	Unnamed	230	225	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
386	Unnamed	231	226	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
387	Unnamed	232	227	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
388	Unnamed	233	228	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
389	Unnamed	234	229	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
390	Unnamed	235	230	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
391	Unnamed	236	231	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
392	Unnamed	237	232	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
393	Unnamed	238	233	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
394	Unnamed	239	234	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
395	Unnamed	240	235	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
396	Unnamed	241	236	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
397	Unnamed	242	237	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
398	Unnamed	243	238	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
399	Unnamed	244	239	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
400	Unnamed	245	240	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
401	Unnamed	306	301	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
402	Unnamed	307	302	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
403	Unnamed	308	303	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
404	Unnamed	309	304	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
405	Unnamed	310	305	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
406	Unnamed	311	306	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
407	Unnamed	312	307	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
408	Unnamed	313	308	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
409	Unnamed	314	309	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
410	Unnamed	315	310	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
411	Unnamed	316	311	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
412	Unnamed	317	312	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
413	Unnamed	318	313	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
414	Unnamed	319	314	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
415	Unnamed	320	315	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
416	Unnamed	321	316	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
417	Unnamed	322	317	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
418	Unnamed	323	318	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000

419	Unnamed	324	319	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000
420	Unnamed	325	320	3100.000000	0.000000	1.000000	0.000000	3100.000000	0.000000	1.000000	0.000000	0.000000	1.000000

FEA Object Group 59: Beam Distributed Loads

Beam Distributed Load

ID	Description	Line ID	Element ID	Magnitude-I	Vx-I	Vy-I	Vz-I	Magnitude-J	Vx-J	Vy-J	Vz-J	A	B
438	Unnamed	157	4	14000.000000	0.000000	1.000000	0.000000	9000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
439	Unnamed	151	3	14000.000000	0.000000	1.000000	0.000000	9000.000000	0.000000	1.000000	0.000000	0.000000	1.000000

FEA Object Group 61: Beam Distributed Loads

Beam Distributed Load

ID	Description	Line ID	Element ID	Magnitude-I	Vx-I	Vy-I	Vz-I	Magnitude-J	Vx-J	Vy-J	Vz-J	A	B
440	Unnamed	106	1	18200.000000	0.000000	1.000000	0.000000	5600.000000	0.000000	1.000000	0.000000	0.000000	1.000000

FEA Object Group 62: Beam Distributed Loads

Beam Distributed Load

ID	Description	Line ID	Element ID	Magnitude-I	Vx-I	Vy-I	Vz-I	Magnitude-J	Vx-J	Vy-J	Vz-J	A	B
441	Unnamed	107	2	5600.000000	0.000000	1.000000	0.000000	3900.000000	0.000000	1.000000	0.000000	0.000000	1.000000

FEA Object Group 65: Beam Distributed Loads

Beam Distributed Load

ID	Description	Line ID	Element ID	Magnitude-I	Vx-I	Vy-I	Vz-I	Magnitude-J	Vx-J	Vy-J	Vz-J	A	B
443	Unnamed	158	5	3900.000000	0.000000	1.000000	0.000000	2500.000000	0.000000	1.000000	0.000000	0.000000	1.000000

FEA Object Group 67: Beam Distributed Loads

Beam Distributed Load

ID	Description	Line ID	Element ID	Magnitude-I	Vx-I	Vy-I	Vz-I	Magnitude-J	Vx-J	Vy-J	Vz-J	A	B
446	Unnamed	159	1	19000.000000	0.000000	1.000000	0.000000	14000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
447	Unnamed	160	2	19000.000000	0.000000	1.000000	0.000000	14000.000000	0.000000	1.000000	0.000000	0.000000	1.000000

FEA Object Group 69: Nodal Forces

Nodal Force

ID	Description	Vertex ID	Node Number	Vx	Vy	Vz	Magnitude	Multiplier Table ID
2	Unnamed	23840	N/A	0.000000	1.000000	0.000000	123716.000000	1
1	Unnamed	23808	N/A	0.000000	1.000000	0.000000	123716.000000	1

FEA Object Group 70: Nodal Forces

Nodal Force

ID	Description	Vertex ID	Node Number	Vx	Vy	Vz	Magnitude	Multiplier Table ID
3	Unnamed	23872	N/A	0.000000	1.000000	0.000000	123261.000000	1
4	Unnamed	23904	N/A	0.000000	1.000000	0.000000	123261.000000	1

FEA Object Group 71: Beam Distributed Loads

Beam Distributed Load

ID	Description	Line ID	Element ID	Magnitude-I	Vx-I	Vy-I	Vz-I	Magnitude-J	Vx-J	Vy-J	Vz-J	A	B
512	Unnamed	7	3	40000.000000	0.000000	1.000000	0.000000	20300.000000	0.000000	1.000000	0.000000	0.000000	1.000000

FEA Object Group 72: Beam Distributed Loads

Beam Distributed Load

ID	Description	Line ID	Element ID	Magnitude-I	Vx-I	Vy-I	Vz-I	Magnitude-J	Vx-J	Vy-J	Vz-J	A	B
513	Unnamed	2	1	5700.000000	0.000000	1.000000	0.000000	3500.000000	0.000000	1.000000	0.000000	0.000000	1.000000

FEA Object Group 73: Beam Distributed Loads

Beam Distributed Load

ID	Description	Line ID	Element ID	Magnitude-I	Vx-I	Vy-I	Vz-I	Magnitude-J	Vx-J	Vy-J	Vz-J	A	B
514	Unnamed	5	2	16300.000000	0.000000	1.000000	0.000000	5700.000000	0.000000	1.000000	0.000000	0.000000	1.000000

FEA Object Group 74: Beam Distributed Loads

Beam Distributed Load

ID	Description	Line ID	Element ID	Magnitude-I	Vx-I	Vy-I	Vz-I	Magnitude-J	Vx-J	Vy-J	Vz-J	A	B
516	Unnamed	3	2	20300.000000	0.000000	1.000000	0.000000	20300.000000	0.000000	1.000000	0.000000	0.000000	1.000000
515	Unnamed	2	1	20300.000000	0.000000	1.000000	0.000000	20300.000000	0.000000	1.000000	0.000000	0.000000	1.000000

FEA Object Group 75: Beam Distributed Loads

Beam Distributed Load

ID	Description	Line ID	Element ID	Magnitude-I	Vx-I	Vy-I	Vz-I	Magnitude-J	Vx-J	Vy-J	Vz-J	A	B
518	Unnamed	5	4	19000.000000	0.000000	1.000000	0.000000	19000.000000	0.000000	1.000000	0.000000	0.000000	1.000000
517	Unnamed	4	3	19000.000000	0.000000	1.000000	0.000000	19000.000000	0.000000	1.000000	0.000000	0.000000	1.000000

FEA Object Group 76: Beam Distributed Loads

Beam Distributed Load

ID	Description	Line ID	Element ID	Magnitude-I	Vx-I	Vy-I	Vz-I	Magnitude-J	Vx-J	Vy-J	Vz-J	A	B
520	Unnamed	7	6	18200.000000	0.000000	1.000000	0.000000	18200.000000	0.000000	1.000000	0.000000	0.000000	1.000000
519	Unnamed	6	5	18200.000000	0.000000	1.000000	0.000000	18200.000000	0.000000	1.000000	0.000000	0.000000	1.000000

FEA Object Group 77: Beam Distributed Loads

Beam Distributed Load

ID	Description	Line ID	Element ID	Magnitude-I	Vx-I	Vy-I	Vz-I	Magnitude-J	Vx-J	Vy-J	Vz-J	A	B
522	Unnamed	9	8	17600.000000	0.000000	1.000000	0.000000	17600.000000	0.000000	1.000000	0.000000	0.000000	1.000000
521	Unnamed	8	7	17600.000000	0.000000	1.000000	0.000000	17600.000000	0.000000	1.000000	0.000000	0.000000	1.000000

FEA Object Group 78: Beam Distributed Loads

Beam Distributed Load

ID	Description	Line ID	Element ID	Magnitude-I	Vx-I	Vy-I	Vz-I	Magnitude-J	Vx-J	Vy-J	Vz-J	A	B
524	Unnamed	11	10	16500.000000	0.000000	1.000000	0.000000	16500.000000	0.000000	1.000000	0.000000	0.000000	1.000000
523	Unnamed	10	9	16500.000000	0.000000	1.000000	0.000000	16500.000000	0.000000	1.000000	0.000000	0.000000	1.000000

FEA Object Group 79: Beam Distributed Loads

Beam Distributed Load

ID	Description	Line ID	Element ID	Magnitude-I	Vx-I	Vy-I	Vz-I	Magnitude-J	Vx-J	Vy-J	Vz-J	A	B
525	Unnamed	12	11	16400.000000	0.000000	1.000000	0.000000	16400.000000	0.000000	1.000000	0.000000	0.000000	1.000000

Constraints

FEA Object Group 4: Nodal Boundary Conditions

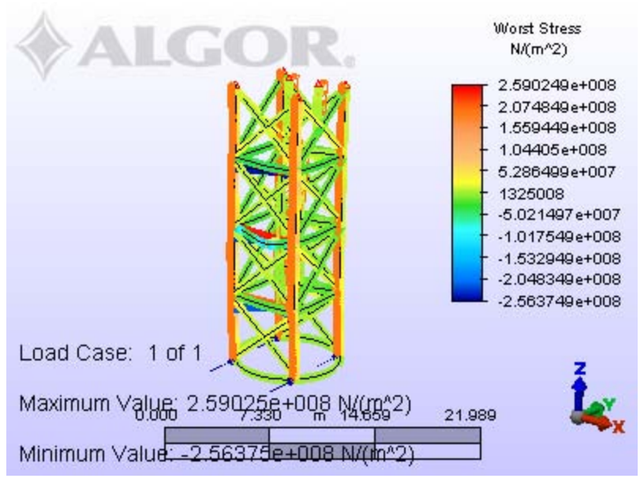
Nodal Boundary Condition

ID	Description	Vertex ID	Node Number	Tx	Ty	Tz	Rx	Ry	Rz
9	Unnamed	10609	13	Yes	Yes	Yes	Yes	Yes	Yes
10	Unnamed	10770	91	Yes	Yes	Yes	Yes	Yes	Yes
11	Unnamed	10931	169	Yes	Yes	Yes	Yes	Yes	Yes
12	Unnamed	11092	247	Yes	Yes	Yes	Yes	Yes	Yes
15	Unnamed	23531	696	Yes	Yes	Yes	Yes	Yes	Yes
16	Unnamed	23534	697	Yes	Yes	Yes	Yes	Yes	Yes

Probes

Probe data was requested, but no probes were detected.

Results Presentation Images



Processor Log Files

Weight & CG Logs

Model Information					
Volume m³	1.66E+002	Weight N	1.28E+007		
Center of Gravity m		Mass moment of inertia N*s²*m		Mass product of inertia N*s²*m	
Xc	-4.05E-005	Ixx	1.36E+009	Ixy	6.46E-318
Yc	-1.67E-001	Iyy	1.35E+009	Ixz	1.05E+292
Zc	-2.93E+001	Izz	5.14E+007	Iyz	6.89E-313

Part Information

Part ID	Part	Volume m³	Weight N	Xc m	Yc m	Zc m
2	Horizontals	1.46E+000	1.12E+005	-2.98E-017	4.96E-017	-2.00E+001
3	Verticals	1.84E+001	1.42E+006	-6.30E-018	-1.95E-016	-2.00E+001
4	Diagonals	7.57E+000	5.84E+005	1.51E-016	8.03E-017	-1.79E+001
5	CW/WW Foundations	2.94E+000	2.26E+005	-2.29E-003	1.88E-002	-2.04E+001
6	Soft Tank	8.48E+001	6.54E+006	1.20E-015	-1.02E-015	-4.00E+001
7	CW Duct	5.91E+000	4.56E+005	0.00E+000	2.90E+000	-1.77E+001
8	WW Duct	8.74E+000	6.74E+005	0.00E+000	-1.90E+000	-2.14E+001
9	CW Hx	9.55E+000	7.36E+005	0.00E+000	2.90E+000	-3.50E+000
10	WW Hx	2.67E+001	2.06E+006	0.00E+000	-2.10E+000	-2.08E+001

Part Information (continued)

Part ID	Part	Ixx N*s²*m	Iyy N*s²*m	Izz N*s²*m	Ixy N*s²*m	Ixz N*s²*m	Iyz N*s²*m
2	Horizontals	5.56E+006	5.56E+006	4.30E+005	-9.09E-013	1.86E-010	1.64E-011
3	Verticals	8.10E+007	8.10E+007	8.12E+006	1.82E-011	3.93E-010	-3.93E-010
4	Diagonals	2.69E+007	2.67E+007	2.23E+006	1.42E-011	4.27E-011	-5.82E-011
5	CW/WW Foundations	1.15E+007	1.14E+007	5.70E+005	1.82E+002	2.31E+003	-1.27E+004
6	Soft Tank	1.08E+009	1.08E+009	3.74E+007	-1.05E-009	-1.82E-008	6.11E-009
7	CW Duct	1.78E+007	1.74E+007	4.16E+005	0.00E+000	0.00E+000	-2.39E+006
8	WW Duct	3.55E+007	3.53E+007	2.50E+005	0.00E+000	0.00E+000	2.72E+006
9	CW Hx	1.86E+006	1.69E+006	1.10E+006	0.00E+000	0.00E+000	-7.61E+005
10	WW Hx	9.17E+007	9.08E+007	9.24E+005	0.00E+000	0.00E+000	9.13E+006

Meshing Log

No Meshing Logs Found.

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-26
Bilge and Ballast Information
OTEC-2010-001

17 September 2010

Prepared for:

Naval Facilities Engineering Command
Naval Facilities Engineering Service Center (NFESC)
1100 23rd Avenue
Port Hueneme, CA 93043-4370
Attn: Mr. Brian Cable, Contracting Officer Representative

Prepared by:

Lockheed Martin MS2
9500 Godwin Drive
Manassas, VA 20110

Distribution Statement A: Approved for public release; distribution is unlimited

APPENDIX 3.3.2.1.1-15

Remora Iteration 2.1—Bilge/Ballast Pump Data

AUXILIARY SYSTEM NOTES

Bilge System

ABS FPI §5B.3.6.1.1

- Fixed bilge system may be omitted for void spaces
- Portable pumps “lowered into spaces through manholes”
- At least 2 portable pumps, with hoses and accessories, at to be available
- For bilge suction sizing use ABS MODU §4.2.4.9.3

ABS MODU §4.2.4

- 2 bilge pumps required
- Void compartments to be drained by permanently installed bilge or by portable means
- If portable—2 pumps required

  §5

- “The arrangement of the bilge pumping system is to be such as to prevent...the possibility of water...passing...from one compartment to another.”

  §7.3 Defines speed of water through bilge main

- Refers to §4.2.4.9.1 and §4.2.4.9.3

  §9.1

- Defines minimum internal pipe diameter for both main and branch lines for Surface-Type Units

  §9.3

- Defines minimum internal pipe diameter for both main and branch lines for Column-Stabilized Units and Self-Elevating Units
- Cross-sectional area not to be less than that required by §4.2.4.9.1.1 (Surface-Type Units)

Ballast System

ABS FPI §5B.3.6.1.3

- Required to have ballast capability for upright to 5° in any direction
- 2 ballast pumps on each ballast tank, one of which is permanently connected

ABS MODU §4.2.4.13

- 2 independent to be capable of taking suction on each ballast tank
-

Vents

ABS FPI §5B.3.6.1.5

- All voids and tanks (except small ones) to be fitted with vents
- Vent opening for hull voids maybe sealed off at spar deck level by means of a blank, if:
  - Voids are below WL
  - Voids above WL to be fitted with rupture disk to account for thermal loads
  - Voids not classified as hazardous areas
  - Voids not fitted with permanently installed bilge or drainage system
  - Voids are fitted with high bilge water level alarm
  - Blank installed in readily accessible position and can be removed for routine de-watering and inspections
  - Voids do not contain pressurized piping

ABS MODU §4.2.4.3

- §4.2.3.1.5 defines vent pipe height and wall thickness
- §4.2.3.1.7 defines vent pipe diameter

Fire-Fighting

ABS FPI §5B.3.6.1.5

- Refers to MODU §5.2

ABS MODU §4.2.4.3

- §5.2.3.1 lists contents of spaces that require a fixed fire-fighting system. None apply to remora.

						Nearest					
Column-Stabilized & Self-Elevating Units						Commercial					
						Size (sched 40, in)				Inside	
		Lgth (m)	WSA (m^2)	d_{branch} (mm)	d_{main} (mm)	Nominal	OD	ID	Q (m^3/hr)	A (m^2)	V (m/s)
Compt 1		5	117.8	48.34	none	2	2.375	2.067	15.60	0.0022	2.002
Compt 2		5	117.8	48.34	none	2	2.375	2.067	15.60	0.0022	2.002
Compt 3		11.5	271.0	60.39	none	2.5	2.875	2.469	22.26	0.0031	2.002
Compt 4		7.5	176.7	53.58	none	2	2.375	2.067	15.60	0.0022	2.002
Compt 5		10	235.6	58.00	none	2	2.375	2.067	15.60	0.0022	2.002
Pump Capacity (m^3/hr, Gal_{US}/hr)			22.26	5880.48							
Possible Pumps											
		Manufacturer	Model	Gal_{US}/hr)	Wt (kg)	Ht (mm)	W (mm)	Pipe d (mm	Volts	Features	
		Rule	174D	8000	4.9	197	305		12 VDC	non-automatic	
		Prosser	2-1/2 HH	6000	23	457		2" & 3"		submersible	
		Prosser	125	6300	15.9		191		120V or 24	submersible	
		Prosser	9-27000	6000-9000	22.7	457	188	2"	230/1	submersible	

CRANE PUMPS

PROSSER®

Portable Dewatering

70&125

PORTABLE SUBMERSIBLE PUMP

This line of portable dewatering pumps is designed to handle the requirement for pumping high volumes of water and dirty water with up to 1/4" solids. These pumps are perfect for pumping flood water and automatic drainage of standing water when used with a piggy back float switch.

Advantages

- Exceptional performance – Model 70 (.7hp) provides 85gpm and Model 125 (1.25hp) provides 105gpm.
- Portability – Model 70 weighs 30lb and Model 125 weighs 35lb with ergonomically designed lifting handle.
- Job site flexibility – Each model includes a 50' power cord to reach remote locations.
- No control box – Start and run capacitors are in the pump motor shell.
- Generator compatible – Low current requirements means an existing generator can be used.
- Small diameter – Both the 70 & 125 models are only 7.5" in diameter and will fit into a sump basin with ease.
- Dry running capability – Pumps can run dry for extended periods without damage.
- Durability – Pumps can take rough handling at the job site.

Applications

- Excavation
- Construction
- Landscaping
- Agriculture
- Industrial
- Commercial
- Residential
- Decorative water features
- Dewatering emergencies



CRANE PUMPS

PROSSER®

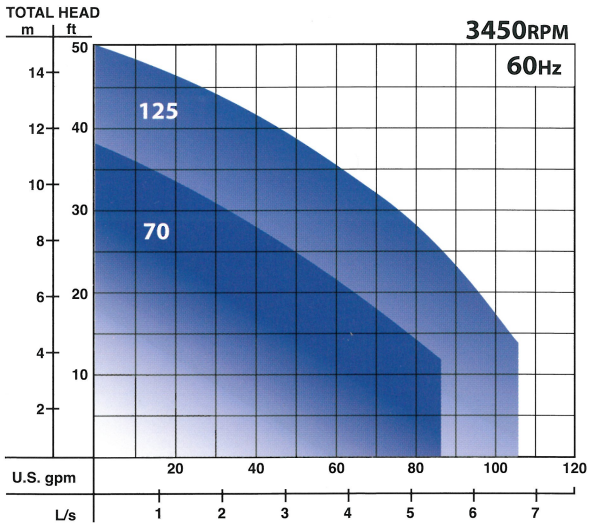
Portable Dewatering

Design Features

- Model 70 units have either a 120v or 240v 1ph motor
- Model 125 units have either 120v or 240v 1ph motor
- Motors are standard with Class F insulation
- Tandem oil lubricated silicon carbide mechanical seals are standard
- Stainless steel motor housing
- Polyurethane wear resistant semi-open impellers and diffusers
- Rubberized strainers for durability
- Dry run capability
- 25′ polypropylene lifting rope provided with pump
- 2″ NPT male discharge connection
- Model 70 can achieve a shutoff head of 38′
- Model 125 can achieve a shutoff head of 50′
- Repair parts are sold in kits



Part No. 115167 ***Part No. 115165***





top view

CRANE PUMPS & SYSTEMS

A Crane Co. Company

For more information contact your Barnes Pump Representative

Crane Pumps & Systems
420 Third Street
Piqua, Ohio 45356
(937) 778-8947
Fax (937) 773-7157
www.cranepumps.com

Crane Pumps & Systems
1485 Lexington Avenue
Mansfield, Ohio 44907
(937) 778-8947
Fax (419) 774-1530

Crane Pumps & Systems Canada
83 West Drive
Brampton, Ont. Canada L6T 2J6
(906) 457-6223
Fax (906) 457-2650

Form PPSD70,125-8/03

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Printed in U.S.A.

I&O Manual

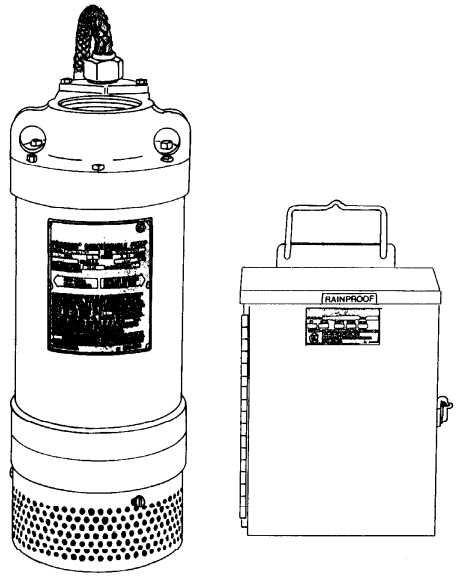
Submersible Dewatering Pumps

DISCHARGE CASE ..... 356T6 Aluminum, Hard Anodized
DIFFUSER ..... 356T6 Aluminum, Hard Anodized
SUCTION CASE ..... 356T6 Aluminum, Hard Anodized, with wear resistant polyurethane liner
FRAME & OUTER CASE ..... 6063T6 Aluminum, Hard Anodized
WEAR PLATE ..... Polyurethane
PUMP SHAFT ..... Stainless Steel
IMPELLER ..... Hardened 17-4 Stainless Steel
HARDWARE ..... Stainless Steel
O-RINGS ..... Buna-N
SEAL *Design* ..... Tandem mechanical, Oil lubricated
INBOARD *Material* ..... Rotating Face - Carbon
Stationary Face - Ceramic
Elastomer - Buna-N
Hardware - 300 Series Stainless
OUTBOARD *Material* ..... Rotating Face - Silicon Carbide
Stationary Face - Silicon Carbide
Elastomer - Viton®
Hardware - 300 Series Stainless
STRAINER ..... 300 series stainless steel, .25" (6.35mm) Holes
UPPER BEARING:
Design ..... Single Row, Shielded, Ball
Lubrication ..... Prelubricated high-temperature grease
Load ..... Radial
LOWER BEARING:
Design ..... Single Row, Shielded, Ball
Lubrication ..... Prelubricated high-temperature grease
Load ..... Radial & Thrust
CORD ENTRY ..... 50Ft. (15m) with Strain Relief and Pressure Grommet for Sealing
MOTOR: *Design* ..... NEMA Design L-Single Phase, Squirrel Cage Induction
Insulation ..... Class F
CONTROL: *Single Phase* ..... Rainproof NEMA 3R. Provides overload and short circuit protection, Start & Run Capacitors, ON-OFF Switch.
OPTIONAL EQUIPMENT ..... Watertight, NEMA 4 Control. Discharge Adapters kits, Carrying Handle, Sludge Strainer, Viton® Seals, and Lift Cord. See accessory section for additional information.

WARRANTY INVALID IF CORRECT PROSSER CONTROL IS NOT USED AT ALL TIMES.

WEIGHT
Pump Only - 50 lbs./ 22.7 kg.
Control - 12 lbs./ 5.4 kg.
Cord - .27 lbs/Ft /.40kg/m

SHIPPING WT./STD. UNIT
Pump, Cord & Control
Domestic - 79 lbs. / 35.8 kg
Export - 114 lbs. / 3.6 Cu. Ft.



Series: 9-27000, 2.75HP, 1Ph

ASSOCIATION OF EQUIPMENT MANUFACTURERS

NRTL\C

CSA 108 - File No. LR16567
UL 778

DESCRIPTION:

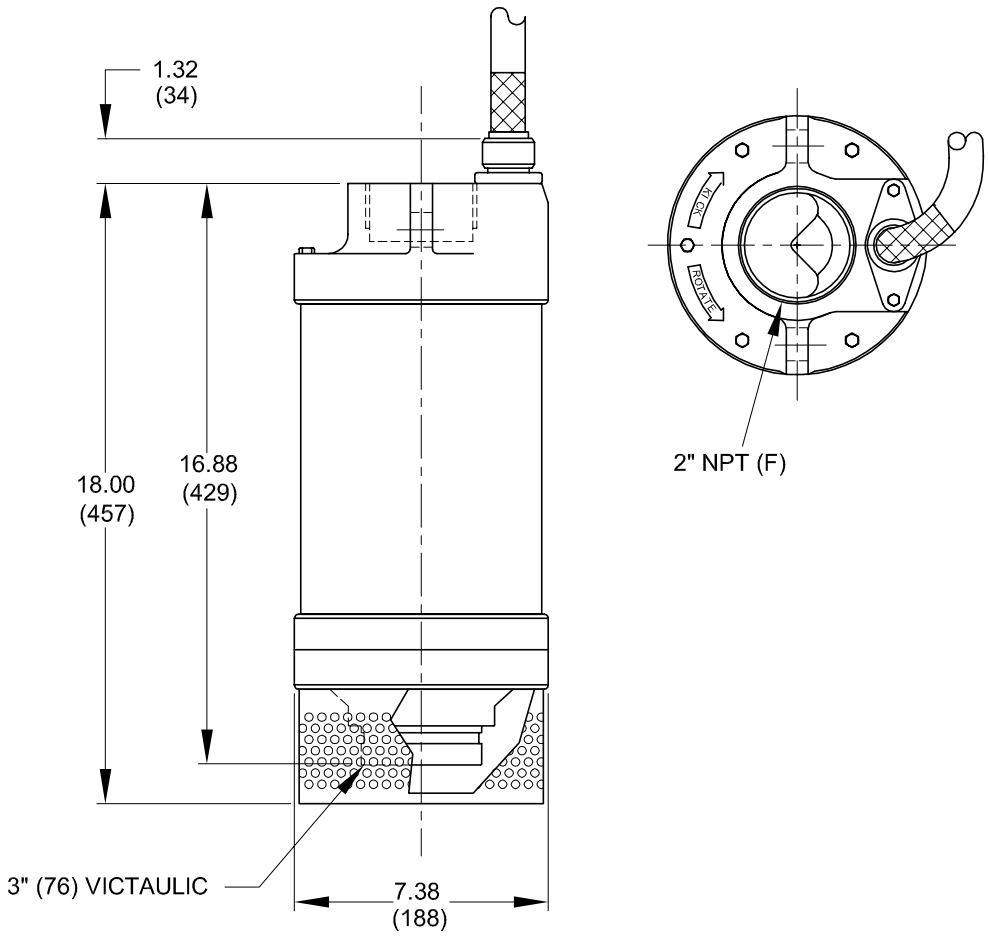
Prosser's small but powerful Portable Electric Submersible Pumps are compact, lightweight units. They are quiet and will operate in any position. No priming, suction hose or foot valves are required. Prosser pumps can be easily staged for higher head applications. The patented outboard shaft seal on this pump is a specially designed silicon carbide abrasive resistant type "S" shaft seal, which offers greater service life. A special abrasion resistant suction case lining and wear plate is a standard feature that protects the pump against wear from abrasive laden water.

The unique in-line design assures a cool running motor with heat transferred to the pumped liquid. Prosser pumps can operate in up to 140°F (60°C) temperature water and within a range of 5 to 9PH.

Before pumping fluids other than water consult the factory, giving fluid, fluid temperature, specific gravity, viscosity, capacity in USGPM and total head and/or pressure requirements, including friction loss through discharge line, fittings, valves, etc.

Submersible Dewatering Pumps

I&O Manual



PART NO.	HP	VOLT/PH	Hz	RPM (Nom.)	NEMA START CODE	FULL LOAD AMPS	LOCKED ROTOR AMPS	CORD SIZE	CORD TYPE	MAX. CORD LENGTH
PUMP w/RAINPROOF CONTROL										
9-27112-03	2.75	230/1	60	3450	D	12.5	52.6	12/4	SOW	197Ft./60m
PUMP w/OPTIONAL WATERTIGHT CONTROL										
9-27112-04	2.75	230/1	60	3450	D	12.5	52.6	12/4	SOW	197Ft./60m

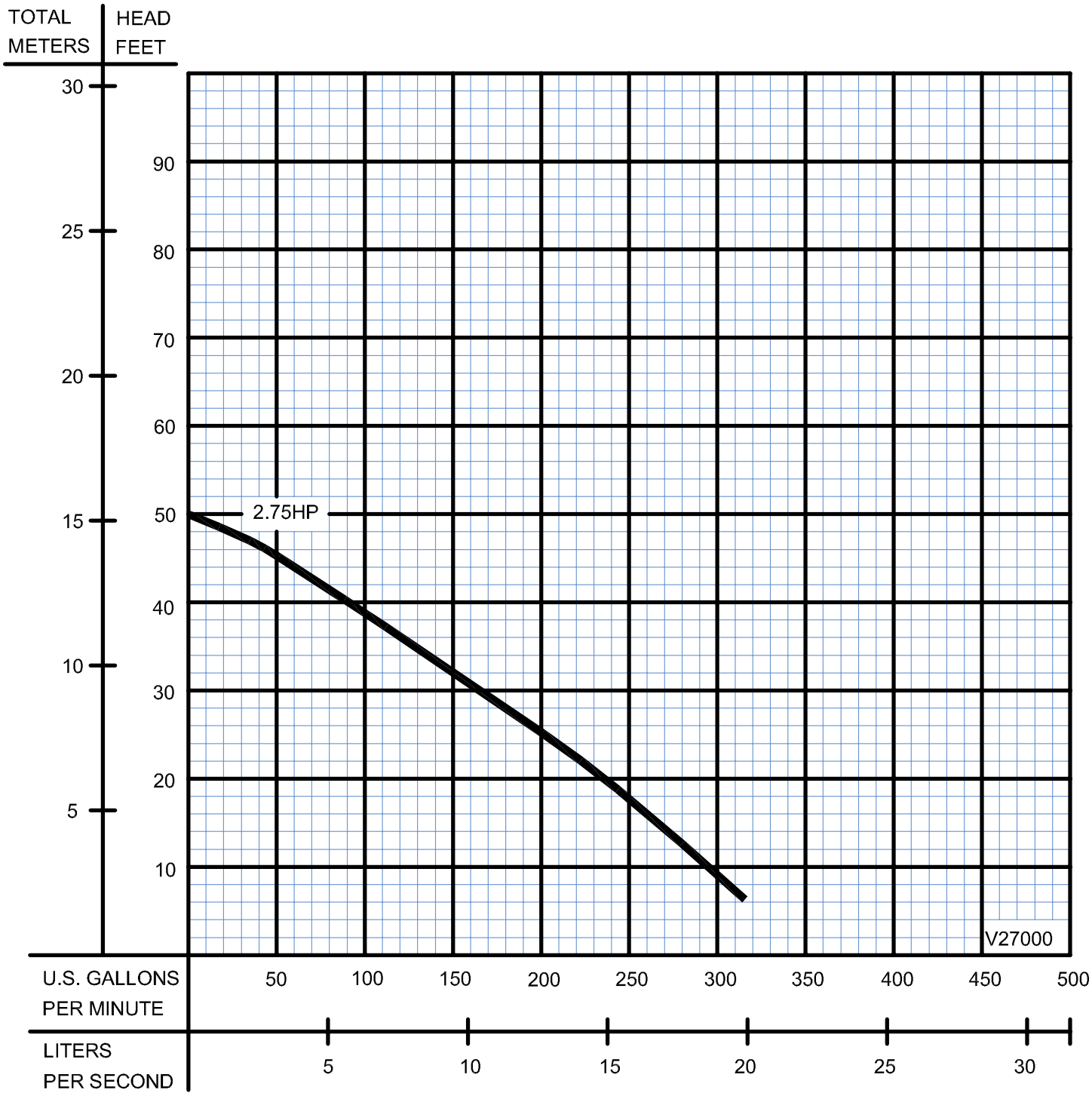
Pump rated for operation at ± 10% voltage at motor.

IMPORTANT !

1.) PUMP MAY BE OPERATED “DRY” FOR EXTENDED PERIODS WITHOUT DAMAGE TO MOTOR AND/OR SEALS.
2.) THIS PUMP IS APPROPRIATE FOR THOSE APPLICATIONS SPECIFIED AS CLASS I DIVISION II HAZARDOUS LOCATIONS. THE CONTROL SUPPLIED WITH THE PUMP IS NOT APPROPRIATE FOR HAZARDOUS LOCATIONS.
3.) THIS PUMP IS NOT APPROPRIATE FOR THOSE APPLICATIONS SPECIFIED AS CLASS I DIVISION I HAZARDOUS LOCATIONS.
4.) INSTALLATIONS SUCH AS DECORATIVE FOUNTAINS OR WATER FEATURES PROVIDED FOR VISUAL ENJOYMENT MUST BE INSTALLED IN ACCORDANCE WITH THE NATIONAL ELECTRIC CODE ANSI/NFPA 70 AND/OR THE AUTHORITY HAVING JURISDICTION. THIS PUMP IS NOT INTENDED FOR USE IN SWIMMING POOLS, RECREATIONAL WATER PARKS, OR INSTALLATIONS IN WHICH HUMAN CONTACT WITH PUMPED MEDIA IS A COMMON OCCURRENCE.

I&O Manual

Submersible Dewatering Pumps



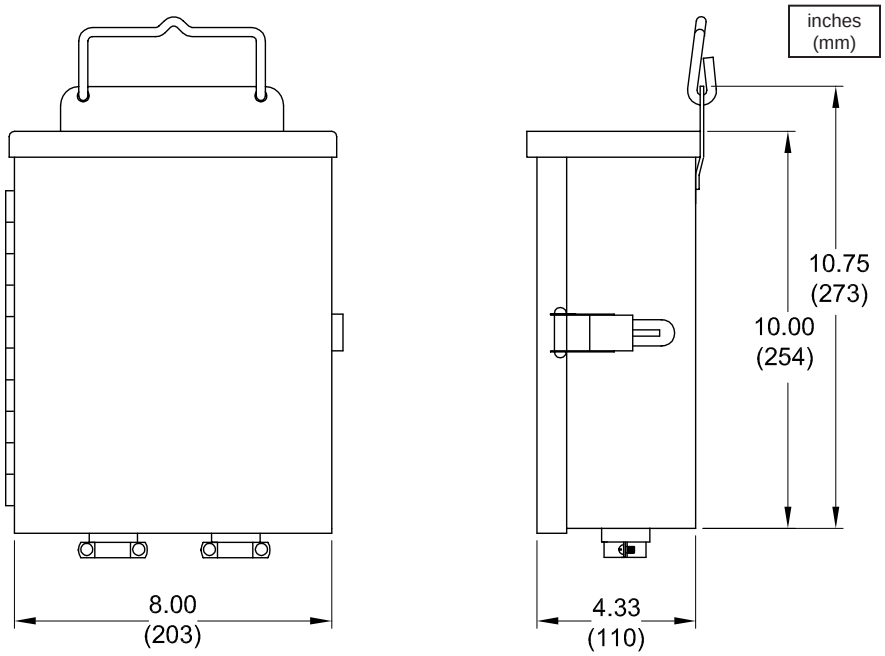
Testing is performed with water, specific gravity 1.0 @ 68º F @ (20°C), other fluids may vary performance

Submersible Dewatering Pumps

I&O Manual

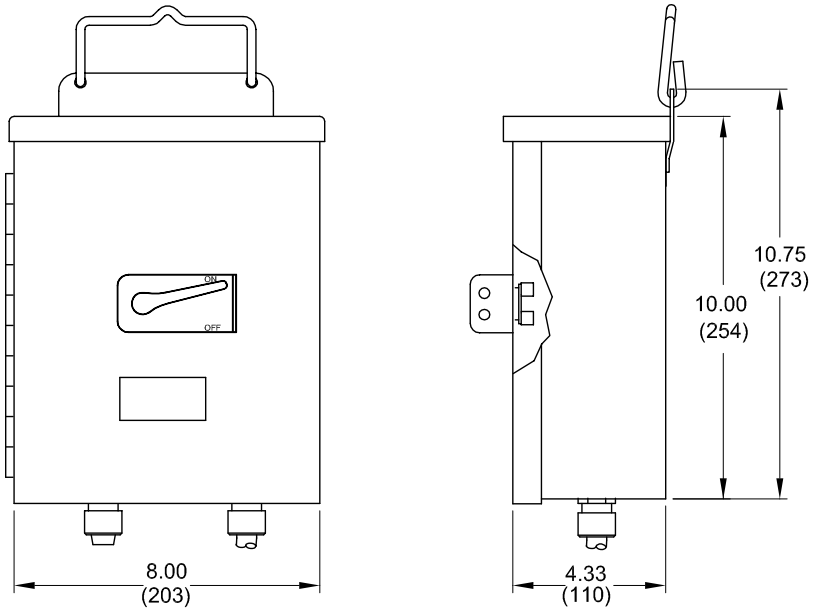
CONTROL
NEMA 3R, RAINPROOF

Pump P/N:	**Control P/N**
9-27112-03	9-270812-03



OPTIONAL - CONTROL
NEMA 4, WATERTIGHT

Pump P/N:	**Control P/N**
9-27112-04	9-270812-04



NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-27
Mating and Demating CONOPS
OTEC-2010-001

17 September 2010

Prepared for:

Naval Facilities Engineering Command
Naval Facilities Engineering Service Center (NFESC)
1100 23rd Avenue
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Attn: Mr. Brian Cable, Contracting Officer Representative

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Manassas, VA 20110

Distribution Statement A: Approved for public release; distribution is unlimited

APPENDIX 3.3.2.1.1-16

Remora Iteration 2.1—Mating/Demating CONOPS

The lower connection bracket consists of a Receiver and Latch on the platform side and a reinforced transverse pin on the Remora side, as shown in Figure 1. The lower connection is designed such that the mating process, connecting remora to platform, simultaneously allows connection of the cold water pipe to the remora and the remora to the platform under varying sea conditions. The lower connection bracket also allows for remora to be

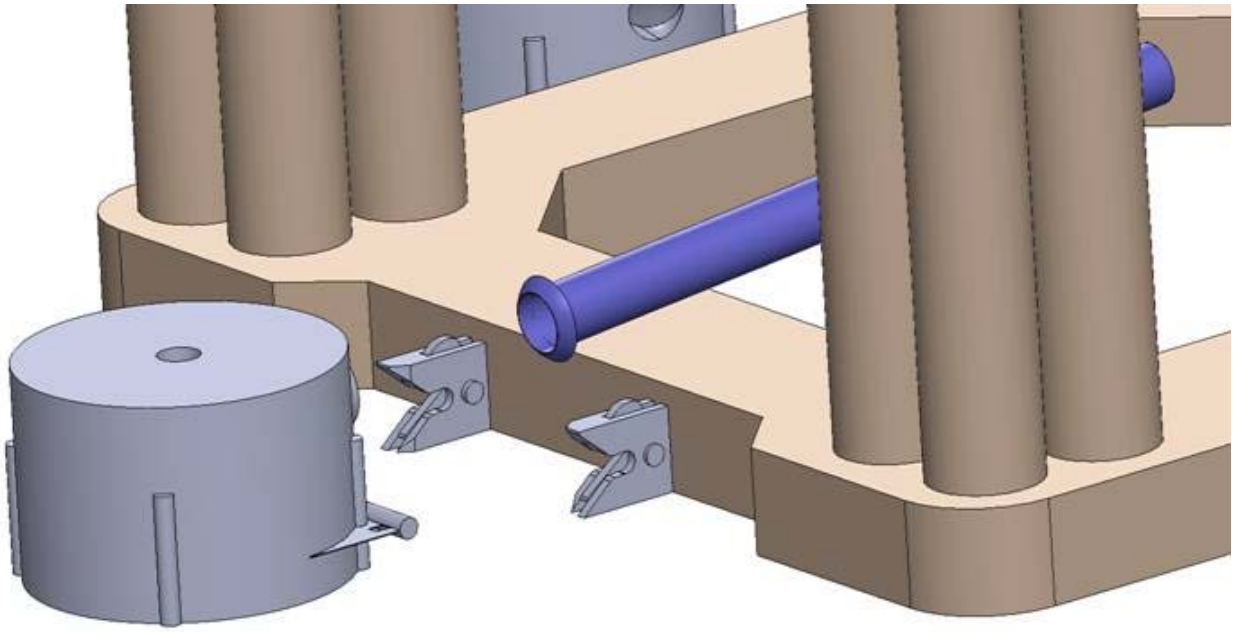


Figure 1. Platform with Cold Water Pipe and Connection Hardware

pushed into the platform using tugboats without the use of a cable and winch system. The method does require, however, that he remora be ballasted to within 0.5m of the design draft.

The receiver is sized such that the remora can heave 2.5 meters, ±1.25m and still allow a positive connection to the remora. The mouth on the receiver is 3m high and tapers down to a 1 meter slot to accept the remora reinforced connection pin as shown in Figure 2. The

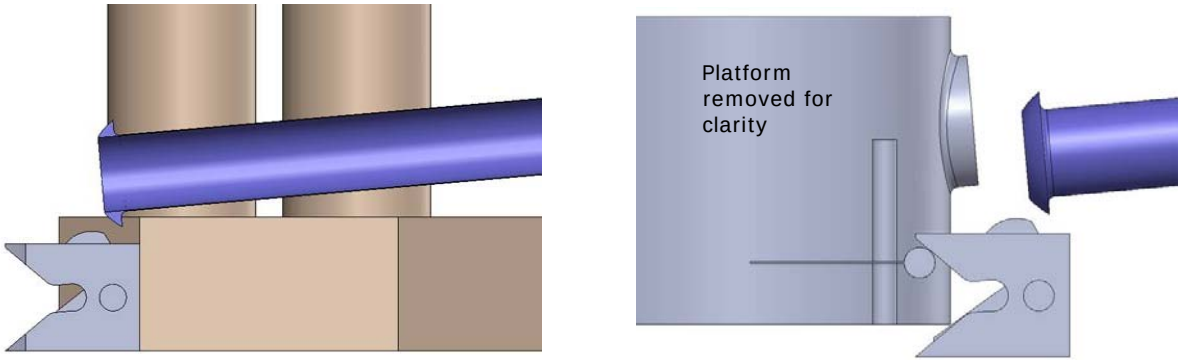


Figure 2. Cold Water Pipe on Platform

slot is angled up at a 5 degree angle to match the angle of the cold water pipe. As the remora approaches the platform the pin will be guided into the mouth of the receiver. If a

wave passes by and causes the remora to heave up or down, the mouth of the receiver will contain the heave motion by the remora connection pin riding along the receiver mouth.

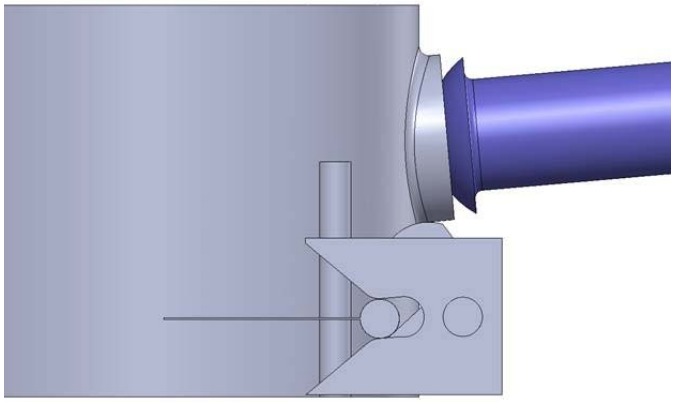


Figure 3. Remora Entering Receiver Slot

Upon continued approach of the remora to the platform, the mouth tapers down into a slot. The slot length and the dual connection receivers restrict the motions of the remora in 3 directions allowing for an aligned mate with the cold water pipe. The cold water pipe is flanged such that it will seat directly into the remora cold water inlet once the remora is captured. The remora is captured by a taper latch as it enters the slot. As the reinforced pin enters the slot it pushes against the latch causing it to tumble capturing and securing the remora as shown in Figure 4.

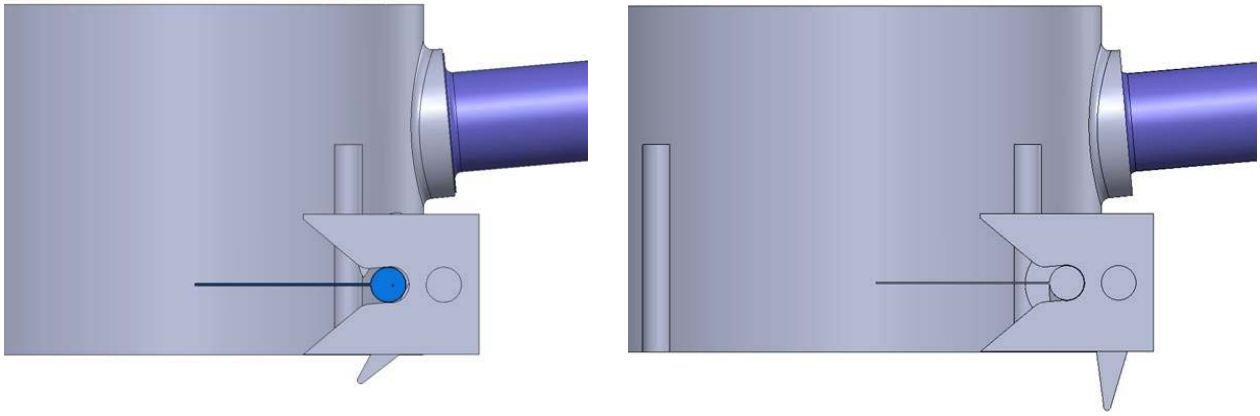


Figure 4. Remora being secured by latch

Because the latch is heavy in water and balanced properly, once the mass center of the latch rotates past the pin center the latch will fall over the remora pin, locking it in place as shown in Figure 5.

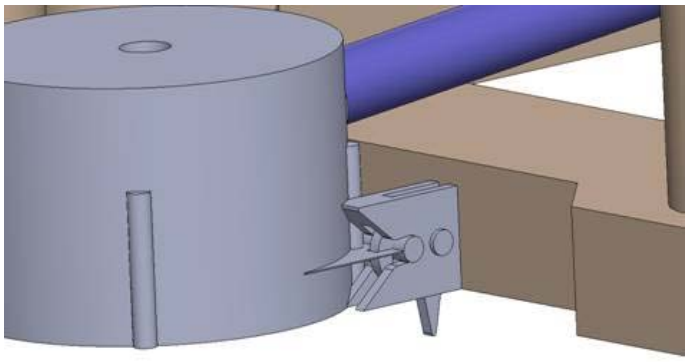


Figure 5. Remora lower connection locked in place.

To reverse the process, upon demating of the remora, a cable is lowered into the water and connected to the tumbler latch. Once connected, the cable will hoist the latch up and over the pin causing it to fall out of the way backwards. Again, because the mass center of the latch crosses over the pin centerline the latch will fall the other way creating an opening in the slot for the remora to be removed.

After the lower connection is made and secured the top of the remora is rotated into the platform where an identical connection is located, locking the top in place.

The cold water connection from the platform to the remora is a positive connection upon mating of the remora to platform, no further secondary connections are necessary, as shown in Figure 6. The cold water pipe enters the remora in one location and splits the flow into 2 identical trunks, allowing flow to 2 independent heat exchangers.

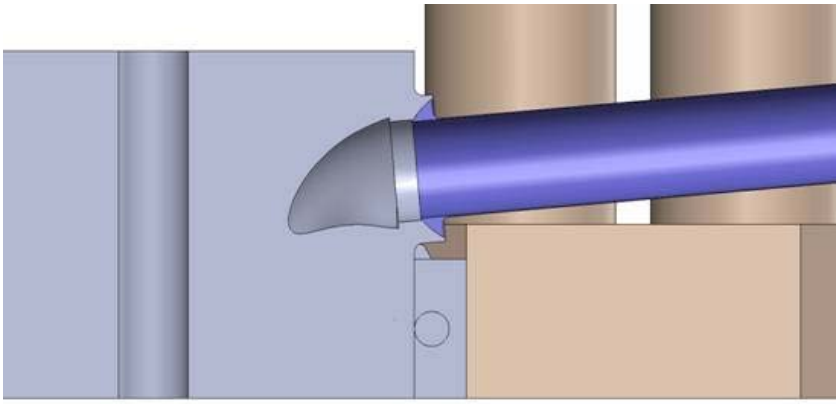


Figure 6. Cold Water Pipe Connection

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-28
Mating and Demating Calculations
OTEC-2010-001

17 September 2010

Prepared for:

Naval Facilities Engineering Command
Naval Facilities Engineering Service Center (NFESC)
1100 23rd Avenue
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Attn: Mr. Brian Cable, Contracting Officer Representative

Prepared by:

Lockheed Martin MS2
9500 Godwin Drive
Manassas, VA 20110

Distribution Statement A: Approved for public release; distribution is unlimited

APPENDIX 3.3.2.1.1-17

Remora Iteration 2.1—Mating/Demating Calculations & Data

Remora Iteration 2.1

Mating/Demating Load Estimates

	m =	342334	kg-m							
	m_A =	0	kg-m							
	Vrms =	0.2321	m/s							
	Vmax =	1.0755	m/s							
	Type "rms" or "max" =	rms								
	KE =	9217	KN-m [KJ]	3399	[ft-Ton]					
	No of Shock Cells =	2								
Total	Total									
Defl	Defl	**KE_T**		**KE/unit**		**F = kx**			Δt	
[in]	[m]	[KN-m]	[ft-Ton]	[KN-m]	[ft-Ton]	[KN]	[Ton]		[s]	
19.7	0.5	36868	13596	18434	6798	9217	3399		0.017	
23.6	0.6	25603	9441	12801	4721	7681	2832		0.021	
27.6	0.7	18810	6937	9405	3468	6584	2428		0.024	
31.5	0.8	14402	5311	7201	2655	5761	2124		0.028	
35.4	0.9	11379	4196	5690	2098	5121	1888		0.031	
39.4	1	9217	3399	4609	1699	4609	1699		0.034	
43.3	1.1	7617	2809	3809	1404	4190	1545		0.038	
47.2	1.2	6401	2360	3200	1180	3840	1416		0.041	
51.2	1.3	5454	2011	2727	1006	3545	1307		0.045	
55.1	1.4	4703	1734	2351	867	3292	1214		0.048	
59.1	1.5	4096	1511	2048	755	3072	1133		0.052	
63.0	1.6	3600	1328	1800	664	2880	1062		0.055	
66.9	1.7	3189	1176	1595	588	2711	1000		0.059	
70.9	1.8	2845	1049	1422	525	2560	944		0.062	
74.8	1.9	2553	942	1277	471	2426	894		0.066	
78.7	2	2304	850	1152	425	2304	850		0.069	

Since the force in the Shock Cell increases from 0 to max while the mass decelerates, the average decelerating force is half of the maximum force.
From this the time can be calculated using the impulse momentum equation.

CASE 20:

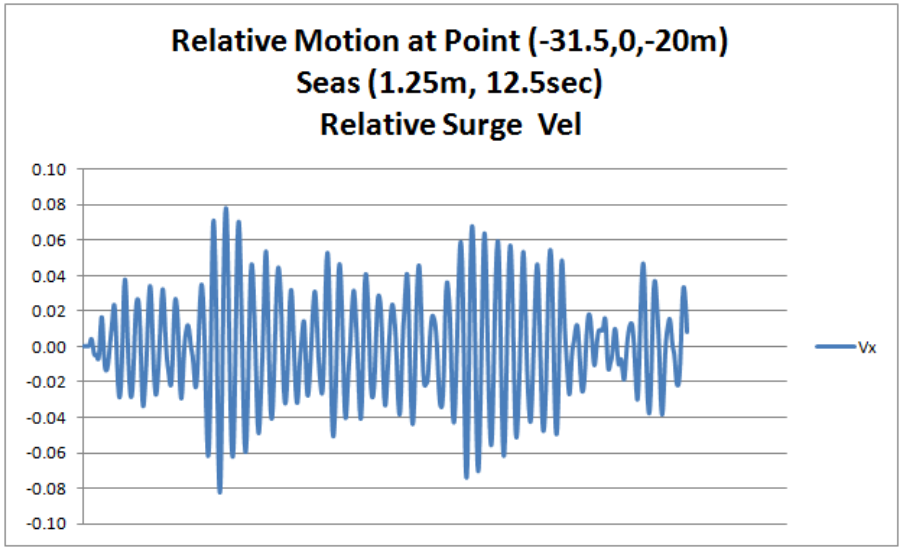
LAMP run Sea State: $H_{1/3}$ = 1.25m, Tmodal = 12.5sec

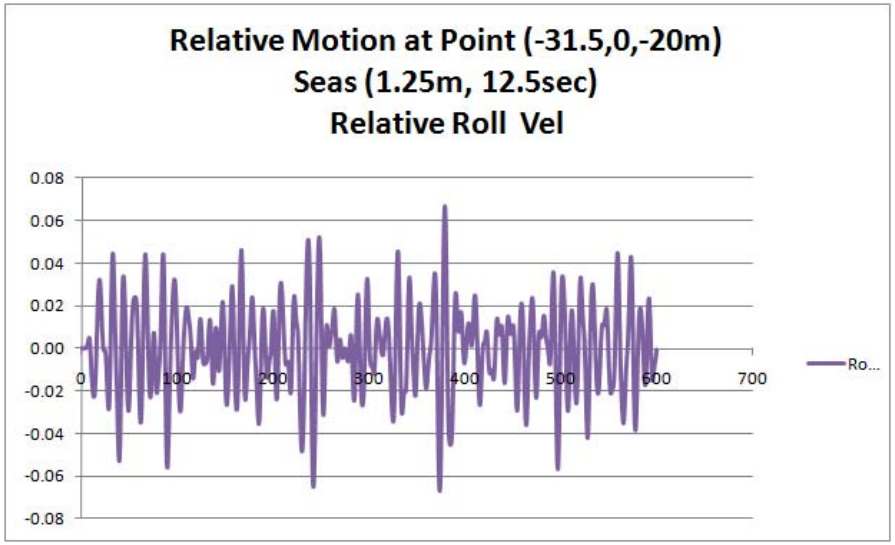
Relative Motion Time History of Velocity of point (-31.5000, 0.0000,-20.00000)

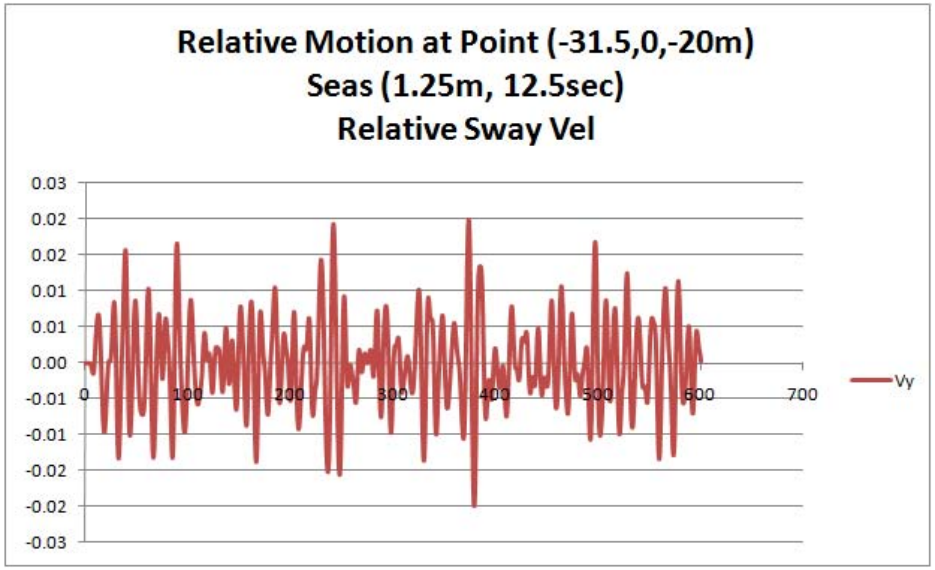
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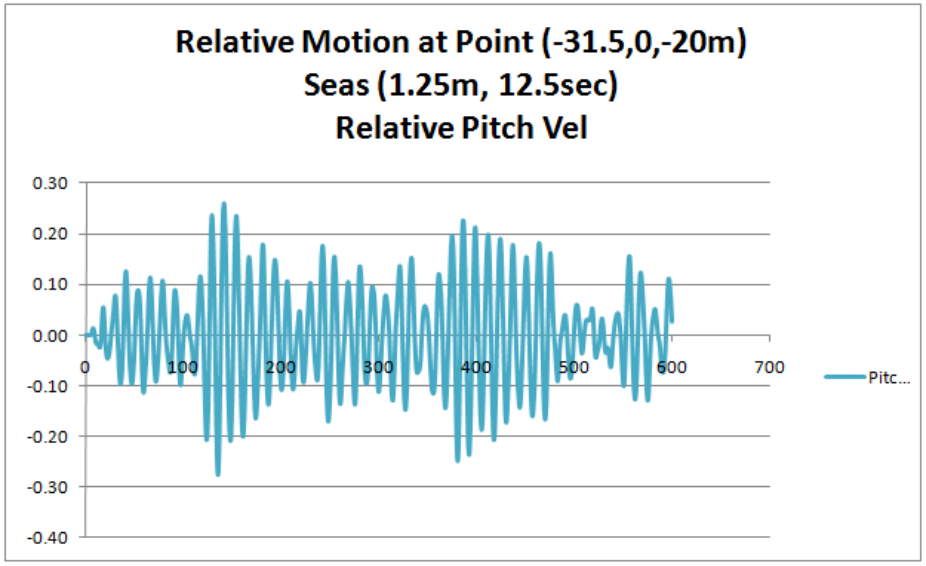
STATS	Vx	Vy	Vz	Roll Rate	Pitch Rate	V	
rms	0.029	0.006	0.397	0.021	0.096	0.232	0.399
4*rms	0.115	0.025	1.590	0.083	0.385	0.928	
max	0.078	0.020	1.033	0.067	0.260	1.075	

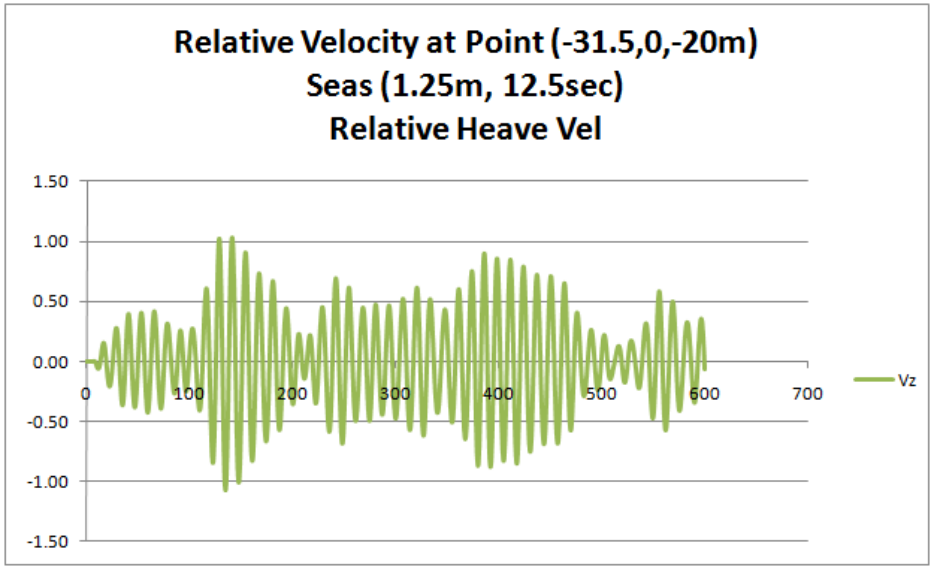
STATS	X	Y	Z	Roll	Pitch
rms	0.019	0.017	0.098	0.084	0.064
4*rms	0.078	0.068	0.394	0.334	0.256

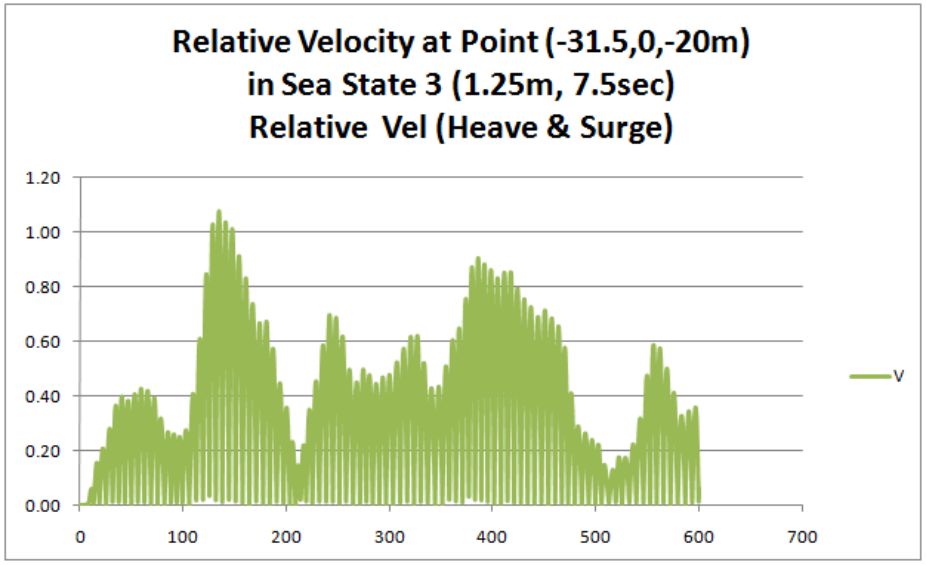





Relative Motion at Point (-31.5,0,-20m)
Seas (1.25m, 12.5sec)
Relative Sway Vel
0.03
0.02
0.02
0.01
0.01
0.00
-0.01
-0.01
-0.02
-0.02
-0.03
0
100
200
300
400
500
600
700
Vy


Relative Motion at Point (-31.5,0,-20m)
Seas (1.25m, 12.5sec)
Relative Pitch Vel
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
0
100
200
300
400
500
600
700
Pitc...

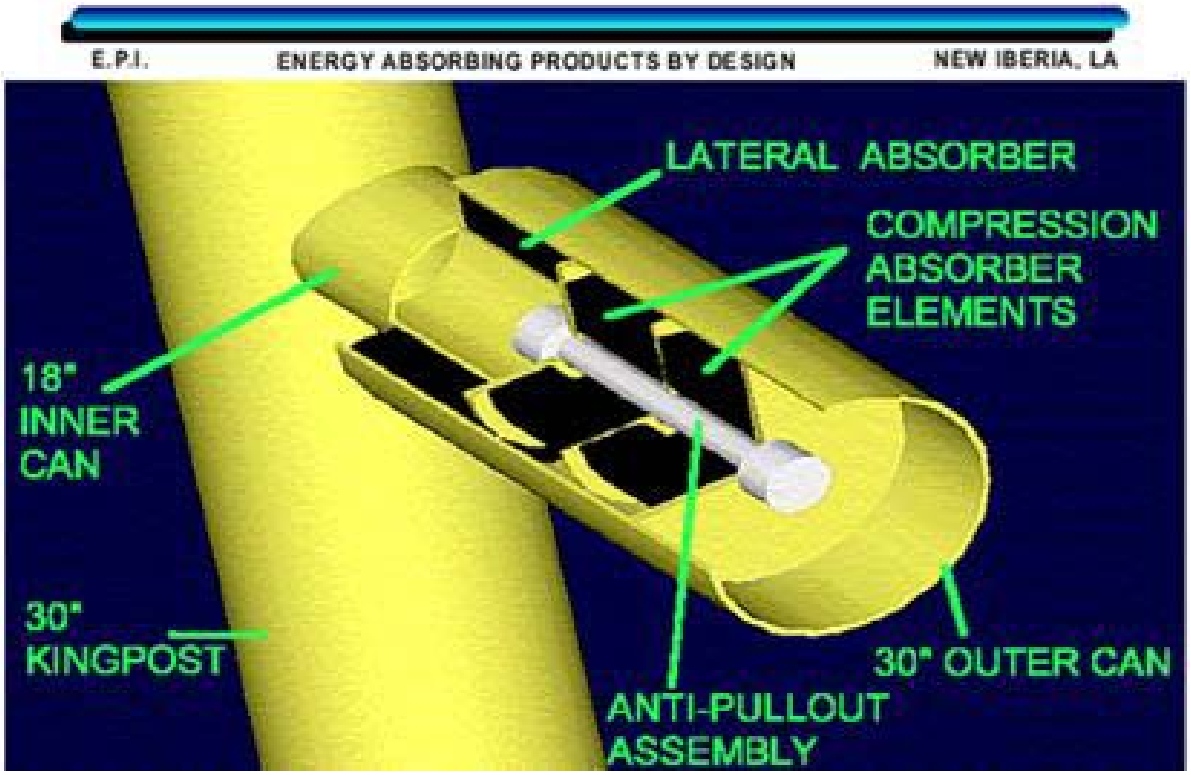

Relative Velocity at Point (-31.5,0,-20m)
Seas (1.25m, 12.5sec)
Relative Heave Vel
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
0
100
200
300
400
500
600
700
Vz

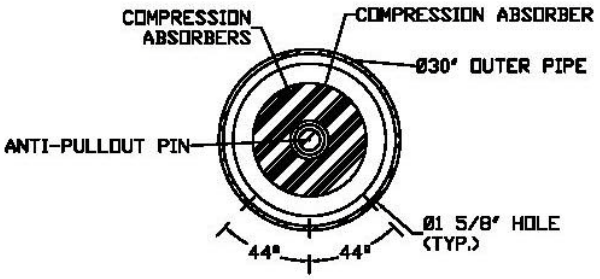

Relative Velocity at Point (-31.5,0,-20m)
in Sea State 3 (1.25m, 7.5sec)
Relative Vel (Heave & Surge)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
100
200
300
400
500
600
700
V

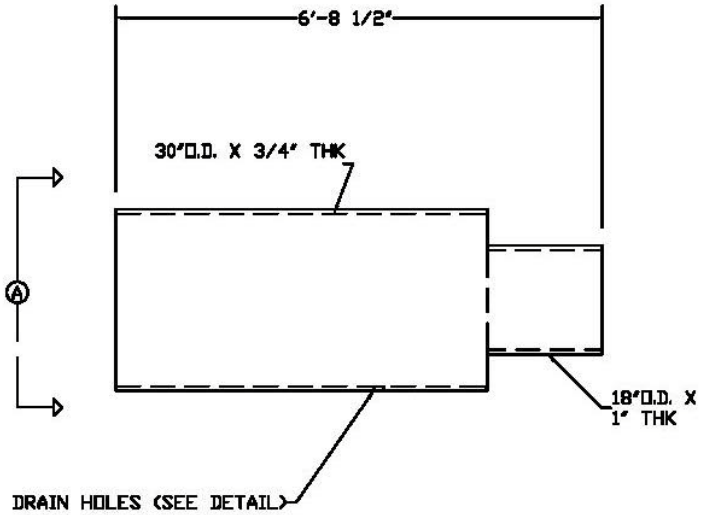
Remora Iteration 2.1

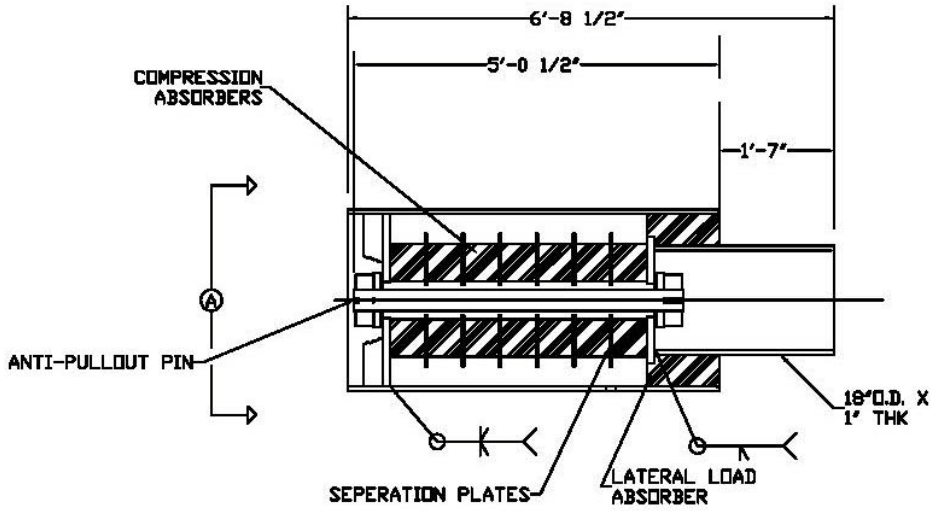
Mating Shock Cell Data

E.P.I. COMPRESSION ABSORBER (SHOCK CELL)









NOTES:

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ENERGY ABSORBING PRODUCTS BY DESIGN
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PROJECT TITLE

EPI SC1830P-7

DOCUMENT TITLE

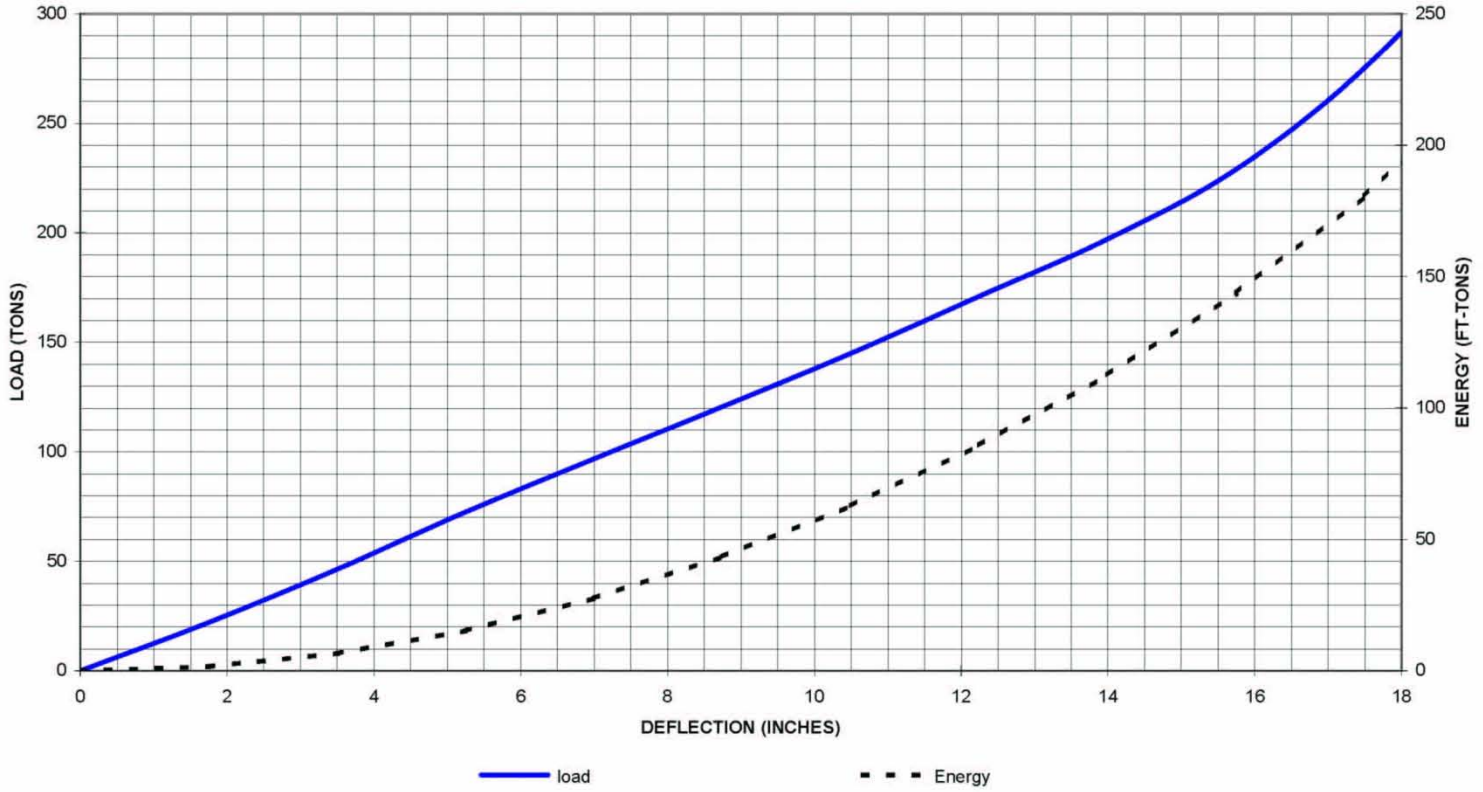
SHOCKCELL DETAILS

DOCUMENT NUMBER			
JOB NO.	DWG. NO.	REV. NO.	DATE
	001	000	7/7/06

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E.P.I. INC.
ENERGY ABSORBING PRODUCTS BY DESIGN

EPI SC1830P-7 AXIAL PERFORMANCE



Performance Tolerance ± 10%

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-29
Corrosion Study
OTEC-2010-001

17 September 2010

Prepared for:

Naval Facilities Engineering Command
Naval Facilities Engineering Service Center (NFESC)
1100 23rd Avenue
Port Hueneme, CA 93043-4370
Attn: Mr. Brian Cable, Contracting Officer Representative

Prepared by:

Lockheed Martin MS2
9500 Godwin Drive
Manassas, VA 20110

Distribution Statement A: Approved for public release; distribution is unlimited

APPENDIX 3.3.2.1.1-18

Remora Iteration 2.1—Corrosion Protection Study, Calculations and Data

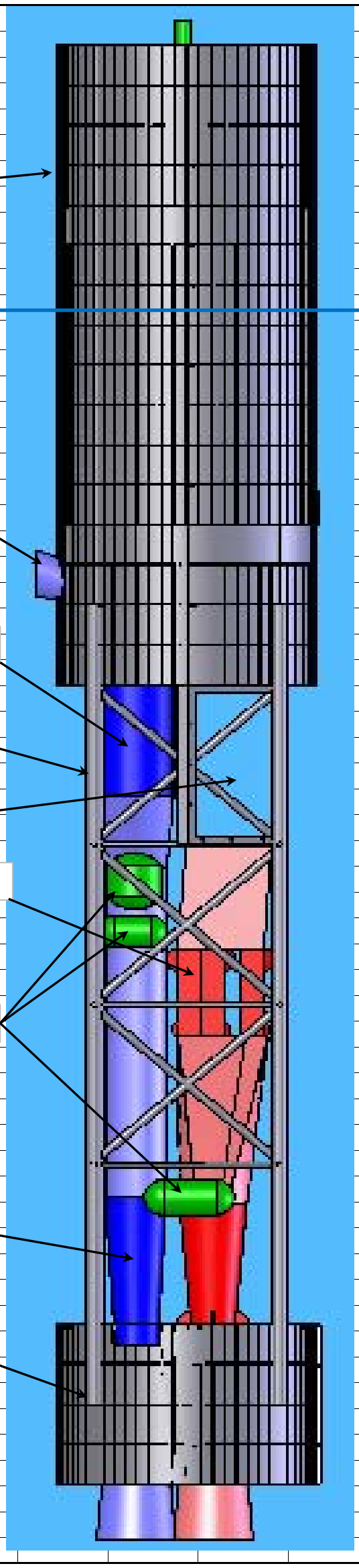
Remora Iteration 2.1

Remora Surface Area Calculation

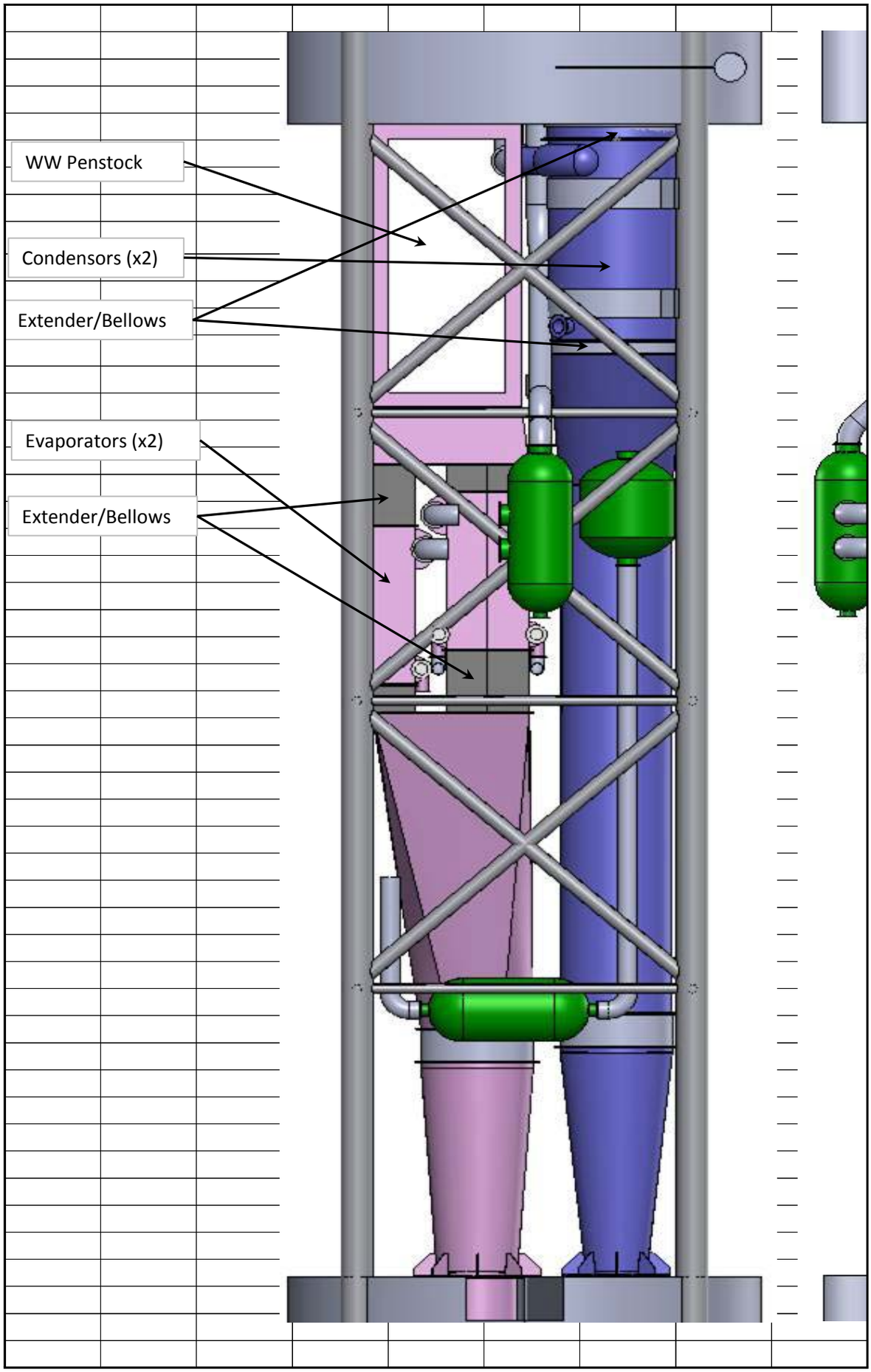
General Arrangement

(Note: arrgt of cold (blue) and warm (red) water systems in this view is dated. See detail views to right for current, more accurate water system arrangements)

LOA (m)	94
$L_{structure}$ (m)	90
OD (m)	15
Freeboard (m)	17



Wetted Surface Areas	(WSA) (m^2)	
Hard Tank	1261	AH36 steel
Condensors	189	Titanium
Penstock	375	AH36 steel
Truss	2538	AH36 steel
CW Trunking	315	AH36 steel
WW Turnking	438	AH36 steel
Evaporators	437	Aluminum
Ammonia Tanks		
Separator	96	AH36 steel
Buffer Tanks	74	AH36 steel
Pump Modules	71	AH36 steel
CW SW Pump	191	steel
WW SW Pump	191	steel
Soft Tank	825	AH36 steel
CW Discharge	134	AH36 steel
WW Discharge	134	AH36 steel


WW Penstock
Condensors (x2)
Extender/Bellows
Evaporators (x2)
Extender/Bellows

Remora Iteration 2.1

Corrosion Protection Study

OTEC Remora Cathodic Protection System Design Calculations

James F. Jenkins, P.E.

16 July 2010

Designed per DNV RP-B-401

Total surface area to be protected = 6832 M^2

Tropical Environment, Water Temp > 20C

Water Depth = < 30 M

Seawater Resistivity = 20 Ohm-cm

Note: The current requirements and coating breakdown factors for 30M to 100 M depth are somewhat less, so these calculations are somewhat conservative.

Mean Current Density Requirement = 0.070 A/M^2

Coating Breakdown Factors

Coating Category	a	b
I	0.10	0.10
II	0.05	0.025
III	0.02	0.012

Coating Categories:

Cat I = One layer of epoxy paint coating min. 20 µm DFT (approx 1 mil)

Cat II = One or more layers of marine paint coating (epoxy, polyurethane or vinyl based, total nominal DFT min. = 250 µm (approx 10 mils)

Cat III = Two or more layers of marine paint coating (epoxy, polyurethane or vinyl based, total nominal DFT min. = 350 µm (approx 14 mils)

The electrochemical capacity of aluminum anodes is 2000 AH/kg

The anode utilization factor for flush mounted anodes is 0.80

The required anode life is 5 years

Note that for longer deployments, the coating breakdown factors will increase and the required anode weight will increase. This design assumes recoating at 5 year intervals.

Mean Current Requirements and Anode Mass Calculations

Bare Steel

I (required) = 0.070 A/M^2 X 6832 M^2 = 478 A

The mass of anode material required is:

$$M_a = \frac{I_{mean} \times t_f \times 8760}{\mu \times \xi}$$

Where:

M_a = anode mass (kg)
t_f = anode life (years)
8760 = constant (hours per year)
μ =anode utilization factor
ξ = electrochemical capacity of anode material (AHr/kg)

$$M_a = \frac{478 \times 5 \times 8760}{0.8 \times 2000} = 13085 \text{ kg} = 28{,}853\#$$

Category I Coated Steel

Coating breakdown factor for 5 years = a + b (tf/2)

(tf = design life)

CBF = 0.1 + 0.1 (5/2) = 0.35

I (required) = 0.070 A/M^2 X 6832 M^2 X 0.35 = 167 A

The mass of anode material required is:

$$M_a = \frac{I_{mean} \times t_f \times 8760}{\mu \times \xi}$$

Where:

M_a = anode mass (kg)
t_f = anode life (years)
8760 = constant (hours per year)
μ =anode utilization factor
ξ = electrochemical capacity of anode material (AHr/kg)

$$M_a = \frac{167 \times 5 \times 8760}{0.8 \times 2000} = 4572 \text{ kg} = 10{,}080 \#$$

Category II Coated Steel

Coating breakdown factor for 5 years = a + b (tf/2)

(tf = design life)

CBF = 0.05 + 0.025 (5/2) = 0.1125

I (required) = 0.070 A/M^2 X 6832 M^2 X 0.1125 = 53.8 A

The mass of anode material required is:

$$M_a = \frac{I_{mean} \times t_f \times 8760}{\mu \times \xi}$$

Where:

M_a = anode mass (kg)
t_f = anode life (years)
8760 = constant (hours per year)
μ =anode utilization factor
ξ = electrochemical capacity of anode material (AHr/kg)

$$M_a = \frac{53.8 \times 5 \times 8760}{0.8 \times 2000} = 1473 \text{ kg} = 3248 \#$$

Category III Coated Steel

Coating breakdown factor for 5 years = a + b (tf/2)

(tf = design life)

CBF = 0.02 + 0.012 (5/2) = 0.05

I (required) = 0.070 A/M^2 X 6832 M^2 X 0.05 = 23.9 A

The mass of anode material required is:

$$M_a = \frac{I_{mean} \times t_f \times 8760}{\mu \times \xi}$$

Where:

M_a = anode mass (kg)
t_f = anode life (years)
8760 = constant (hours per year)
μ =anode utilization factor
ξ = electrochemical capacity of anode material (AHr/kg)

$$M_a = \frac{23.9 \times 5 \times 8760}{0.8 \times 2000} = 654 \text{ kg} = 1443 \#$$

Anode Surface Area and Anode Number Calculations

Category II Coating:

Coating Breakdown Factors:

Initial = a = 0.05
Final = a + b(tf) = 0.05 +0.025 (5) = 0.175

Initial Current Requirement = 0.150 A/M^2

Final Current Requirement = 0.100 A/M^2

(From DNV RP-B-401)

I = Area X Current Requirement X Coating Breakdown Factor

Initial = 6832 M^2 x 0.150 A/M^2 X 0.05 = 51.24 A
Final = 6832 M^2 x 0.100 A/M^2 X 0.175 = 119.6 A

The final current requirement is higher and the anode surface area should be sufficient to provide this final current.

The initial anode selected is an aluminum anode (Galvotek) GA-A-1-29H

This anode is 5" X 2.5" X 24" (127 mm X 64 mm X 619 mm) The total surface area of this anode is 1741 cm^2 (not including the area next to the structure).

The resistance of each anode in seawater with a resistivity of 20 Ohm-cm is:

$R = 0.315 \times 20 / \sqrt{\text{Anode Area}} = 0.315 \text{ X } 20 / 41.72 = 0.15 \text{ Ohms}$

The anode to steel driving potential is:

Protected Steel Potential = - 0.80 V
Anode Potential = -1.0 V
(from DNV RP-B-401)

Driving Potential = - 0.10V - (-0.80V) = 0.25 V

Current Output per Anode = V/R = 0.25 V / 0.15 Ohms =1.67 Amperes

Current Required = 119.6 Amperes

Number of Anodes Required for this Current Requirement is:

119.6 Amperes / 1.67 Amperes/Anode = 72

The number of 29 # anodes required for anode mass is:

3248 # / 29 # / Anode = 112

For the Category II coated steel, the required anode mass requires a larger number of anodes than the required surface area. 112 Anodes are required for a category II coated steel remora.

Category III Coating:

Coating Breakdown Factors:

Initial = a = 0.02
Final = a + b(tf) = 0.02 +0.012 (5) = 0.08

I = Area X Current Requirement X Coating Breakdown Factor

Initial = 6832 M^2 x 0.150 A/M^2 X 0.02 = 20.5 A
Final = 6832 M^2 x 0.100 A/M^2 X 0.08 = 54.65 A

The final current requirement is higher and the anode surface area should be sufficient to provide this final current.
The initial anode selected is an aluminum anode (Galvotek) GA-A-1-29H

This anode is 5" X 2.5" X 24" (127 mm X 64 mm X 619 mm) The total surface area of this anode is 1741 cm^2 (not including the area next to the structure).

The resistance of each anode in seawater with a resistivity of 20 Ohm-cm is:

$R = 0.315 \times 20 / \sqrt{\text{Anode Area}} = 0.315 \text{ X } 20 / 41.72 = 0.15$ Ohms

The anode to steel driving potential is:

Protected Steel Potential = - 0.80 V
Anode Potential = -1.0 V
(from DNV RP-B-401)

Driving Potential = - 0.10V - (-0.80V) = 0.25 V

Current Output per Anode = V/R = 0.25 V / 0.15 Ohms =1.67 Amperes

Current Required = 54.65 Amperes

Number of Anodes Required for this Current Requirement is:

54.65 Amperes / 1.67 Amperes/Anode = 33

The number of 29 # anodes required for anode mass is:

1443 # / 29 # / Anode = 50

For the Category II coated steel, the required anode mass requires a larger number of anodes than the required surface area. 50 Anodes are required for a category III coated steel remora.

OTEC Remora Anode Placement

James F. Jenkins, P.E.

23 July 2010

The exact placement of anodes on the remora will depend on the detailed remora design. However, the number of anodes required to be placed on or near each major component can be estimated from the exposed surface area of the components.

The anodes should be distributed as evenly as possible over the exposed surface of each component.

Assuming Category II Coated Steel

Number of Galvotek GA-A-1-29H Anodes Required = 112

Due to rounding, placement of only 111 anodes is given. Recommend that one additional anode be placed on the hard tank as it is near the surface and most vulnerable to corrosion.

Total Remora Surface Area to be Protected = 6832 M^2

Hard Tank Area = 1261 M^2
Fraction of Total Area = 1261/6832 = 0.185
Number of Anodes = 112 X 0.185 = 20

Condenser Shell (Steel) Area = 189 M^2
Fraction of Total Area = 189/6832 = 0.028
Number of Anodes = 112 X 0.028 = 3

Penstock Area = 375
Fraction of Total Area = 375/6832 = 0.055
Number of Anodes = 112 X 0.055 = 6

Truss Area = 2538 M^2
Fraction of Total Area = 2538/6832 = 0.37
Number of Anodes = 112 X 0.37 = 42
Recommend Even Vertical Spacing of Anodes on Truss

CW Trunking Area = 315 M^2
Fraction of Total Area = 315/6832 = 0.046
Number of Anodes = 112 X 0.046 = 5

WW Trunking Area = 438 M^2
Fraction of Total Area = 438/6832 = 0.064
Number of Anodes = 112 X 0.064 = 7

Evaporators - not protected

Ammonia Tanks (Total) = 241 M^2
Fraction of Total Area = 241/6832 =0.035
Number of Anodes = 112 X 0.035 = 4

CW SW Pump Area = 191 M^2
Fraction of Total Area = 191/6832 = 0.028
Number of Anodes = 112 X 0.028 = 3

WW SW Pump Area = 191 M^2
Fraction of Total Area = 191/6832 = 0.028
Number of Anodes = 112 X 0.028 = 3

Soft Tank Area = 825 M^2
Fraction of Total Area = 825/6832 = 0.121
Number of Anodes = 112 X 0.121 = 14

CW Discharge Area = 134 M^2
Fraction of Total Area = 134/6832 = 0.020
Number of Anodes = 112 X 0.020 = 2

WW Discharge Area = 134 M^2
Fraction of Total Area = 134/6832 = 0.020
Number of Anodes = 112 X 0.020 = 2

Assuming Category III Coated Steel

Number of Galvotek GA-A-1-29H Anodes Required = 50

Due to rounding, 51 anodes are listed. It is recommended that this number of anodes be used with the category III coating.

Total Remora Surface Area to be Protected = 6832 M^2

Hard Tank Area = 1261 M^2
Fraction of Total Area = 1261/6832 = 0.185
Number of Anodes = 50 X 0.185 = 9

Condenser Shell (Steel) Area = 189 M^2
Fraction of Total Area = 189/6832 = 0.028
Number of Anodes = 50 X 0.028 = 1.4 (say 2)

Penstock Area = 375
Fraction of Total Area = 375/6832 = 0.055
Number of Anodes = 50 X 0.055 = 2.7 (say 3)

Truss Area = 2538 M^2
Fraction of Total Area = 2538/6832 = 0.37
Number of Anodes = 50 X 0.37 = 18
Recommend Even Vertical Spacing of Anodes on Truss

CW Trunking Area = 315 M^2
Fraction of Total Area = 315/6832 = 0.046
Number of Anodes = 50 X 0.046 = 2

WW Trunking Area = 438 M^2
Fraction of Total Area = 438/6832 = 0.064
Number of Anodes = 50 X 0.064 = 3

Evaporators - not protected

Ammonia Tanks (Total) = 241 M^2
Fraction of Total Area = 241/6832 = 0.035
Number of Anodes = 50 X 0.035 = 2

CW SW Pump Area = 191 M^2
Fraction of Total Area = 191/6832 = 0.028
Number of Anodes = 50 X 0.28 = 1.4 (say 2)

WW SW Pump Area = 191 M^2
Fraction of Total Area = 191/6832 = 0.028
Number of Anodes = 50 X 0.028 = 1.4 (say 2)

Soft Tank Area = 825 M^2
Fraction of Total Area = 825/6832 = 0.121
Number of Anodes = 50 X 0.121 = 6

CW Discharge Area = 134 M^2
Fraction of Total Area = 134/6832 = 0.020
Number of Anodes = 112 X 0.020 = 1

WW Discharge Area = 134 M^2
Fraction of Total Area = 134/6832 = .020
Number of Anodes = 112 X 0.20 = 1

Aluminum
Hull Anodes

For use on hulls of ships, tugs, barges, etc., operating in seawater. All anodes are faired or tapered to minimize turbulence. Anodes are produced with mild steel core straps.

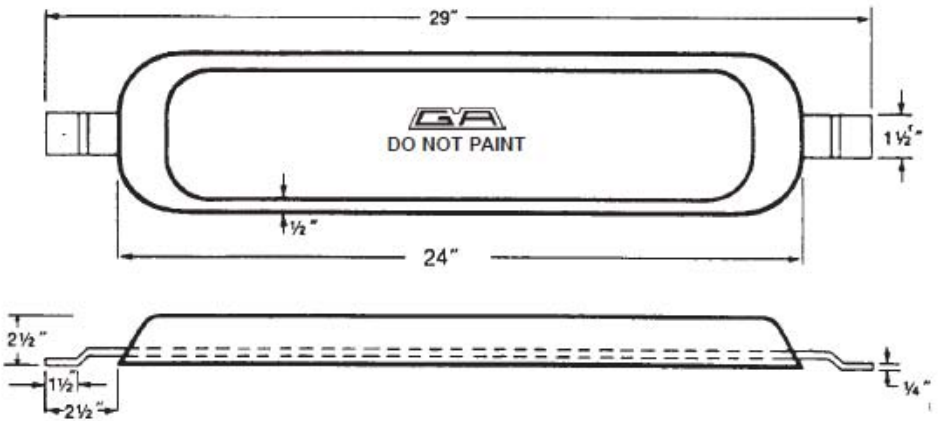
Note – Internal Cores are All Continuous Mild Steel.

GA-A-1-29H

Wt./Anode
29 lbs.
13.2 Kg

Nom. Dimensions
5" x 2 1/2" x 24"
127mm x 64mm x 619mm

Current Rating
4 Ampere – Years



WSA (m^2)		6832				
Intersleek 737 SG		1.21				
Coating		Minimum Coating	Paint	Quantity	Weight	Total
Category	Definition	Thickness (µm)	Weight (kg)	of Anodes	of Anodes (kg)	Treatment Wt (kg)
Bare	No coating	0	0	990	13085	13085
I	1 layer epoxy coating	20	20	346	10080	10100
II	1+ layer epoxy coating	250	2463	112	4572	7035
III	2+ layer epoxy coating	350	3448	50	1473	4921

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-30
Seawater Temperature NavFac OTEC
OTEC-2010-001

17 September 2010

Prepared for:

Naval Facilities Engineering Command
Naval Facilities Engineering Service Center (NFESC)
1100 23rd Avenue
Port Hueneme, CA 93043-4370
Attn: Mr. Brian Cable, Contracting Officer Representative

Prepared by:

Lockheed Martin MS2
9500 Godwin Drive
Manassas, VA 20110

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MAKAI OCEAN ENGINEERING, INC.
P0 Box 1206, Kailua, Hawaii 96734 - USA
(808) 259-8871 FAX: (808) 259-8238

Date: Dec 3, 2009

MEMO

TO: NavFAC OTEC Project Team

From: Steven Rizea

Subject: Kahe HOTS Temperature Data for NavFac OTEC Project

The University of Hawaii has been collecting temperature profile data as part of research cruises off the west coast of Oahu since 1947. Most of the data collection has been a part of Hawaii Ocean Temperature Series (HOTS) study initiated in 1988. Since 2004, the station for data collection (known as the Kahe Station) has been located at 21^{o} 20.6'N, 158^{o} 16.3'W. Makai obtained data from XBT casts west of Oahu between 1947 and 2004. All data that was collected within 2 statute miles of the Kahe HOTS station (a total of 144 casts) was compiled for the following analysis.

The data were analyzed at six different depths: 20m, 30m, 700m, 800m, 900m, and 1000m. The analysis is presented in the following order:

1. Maximum, minimum, and average temperature profiles as seen in the data
2. Correlations between time of year and observed temperature
3. Overview of statistical methods used in the analysis
4. Recommended maximum, minimum and average temperatures for design

Of primary interest to the design team: All figures, Tables 4, 7, and 19

Temperature Profiles

Average, maximum, and minimum recorded temperatures:

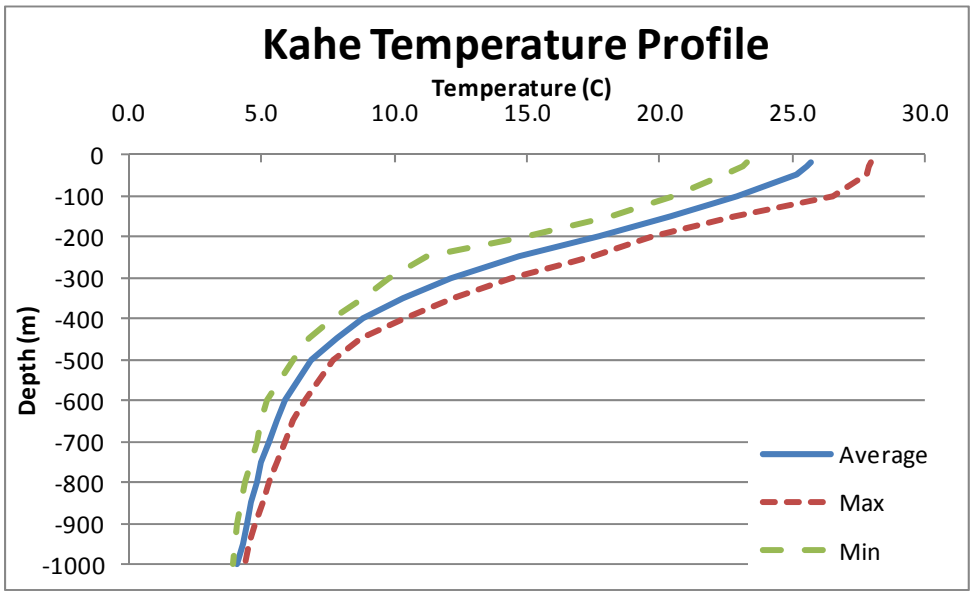


Figure 1: *Temperature Profile at Kahe HOTS Site*

Depth [m]	Max Temp [C]	Avg Temp [C]	Min Temp [C]
-20	28.00	25.70	23.28
-30	27.86	25.56	23.14
-50	27.85	25.17	22.43
-100	26.56	22.90	20.53
-150	22.87	20.43	18.17
-200	19.79	17.73	15.00
-250	17.46	14.73	11.21
-300	14.40	12.16	9.77
-350	12.22	10.33	8.83
-400	10.38	8.86	7.68
-450	8.74	7.84	6.76
-500	7.67	6.90	6.16
-600	6.63	5.89	5.22
-650	6.20	5.56	5.01
-700	5.91	5.25	4.80
-750	5.61	4.98	4.62
-800	5.32	4.79	4.38
-850	5.02	4.62	4.24
-900	4.73	4.45	4.11
-950	4.56	4.28	4.03
-1000	4.38	4.11	3.90

Table 1: *Temperature Profile at Kahe HOTS Site*

Seasonal Correlation at 20m

At 20m depth, there is a strong correlation between time of year and temperature.

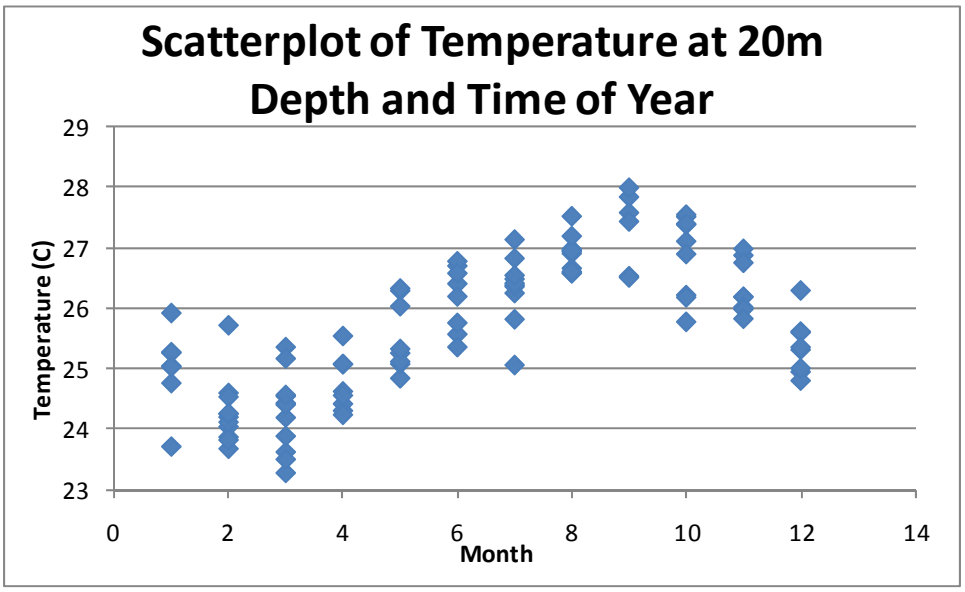


Figure 2: *Scatterplot Showing Correlation between Temperature at 30m Depth and Time of Year*

Seasonal Correlation at 30m

At 30m depth, there is a strong correlation between time of year and temperature.

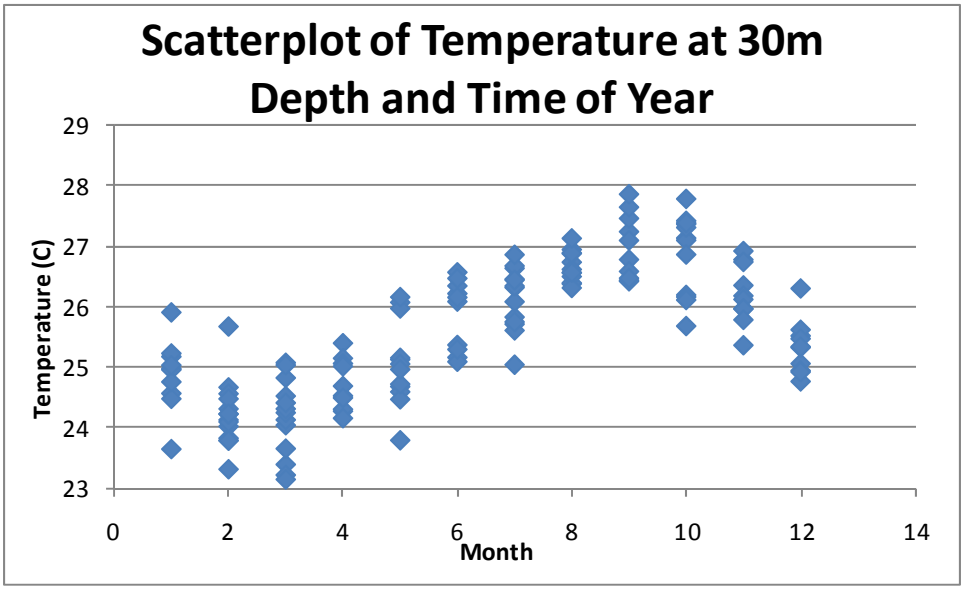


Figure 3: *Scatterplot Showing Correlation between Temperature at 30m Depth and Time of Year*

Seasonal Correlation at 700m

At 700m depth, there is no correlation between time of year and temperature. This was confirmed using Excel's correlation test (in the Analysis Toolpack). The correlation coefficient was -0.05. A coefficient of 0 assures lack of correlation, and any value between 0.1 and -0.1 is typically considered indicative of uncorrelated data. Note that the test only considers linear correlation, but the scatterplot supports the conclusion.

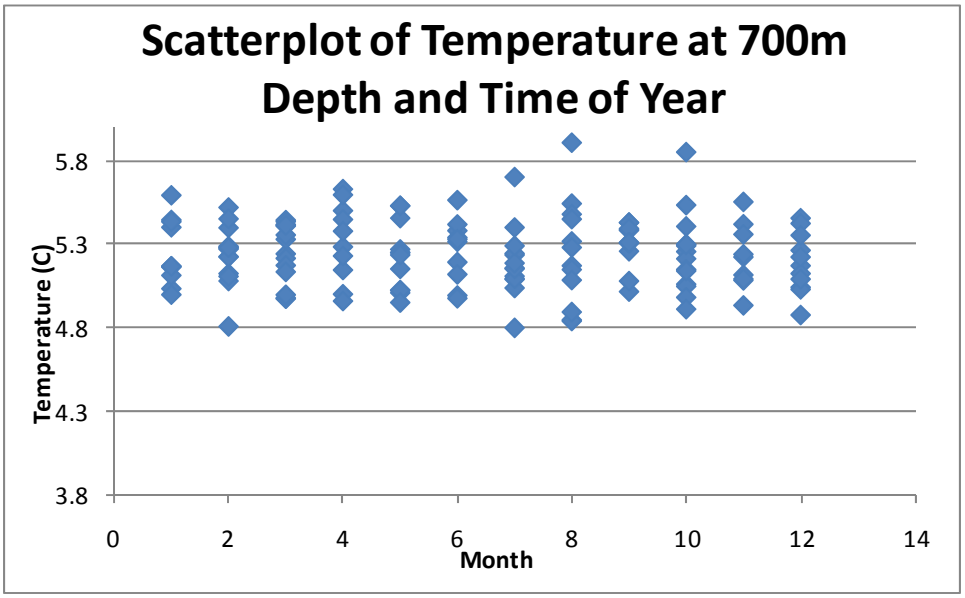


Figure 4: *Correlation between Temperature at 700m Depth and Time of Year*

Lack of correlation at 700m implies lack of correlation at deeper depths. This was confirmed by checking the correlation coefficient at 1000m depth (the value is -0.01). As expected, the value is lower than that found at 700m depth. Therefore, there is no correlation between time of year and seawater temperature for all depths between 700m and 1000m.

Statistical Evaluation of Temperatures at 20m

Since the 20m depth data are influenced by season, we don't have much data upon which to make predictions (between 6 and 11 data points per month). If the real seawater temperature distribution is assumed to be approximately normal, the following predictions can be made (all at 95% confidence level). Note that the following analysis assumes that the annual mean temperature is constant; there is no overall warming or cooling trend over time.

Month	Mean Temp [C]	+/- [C]
Jan	25.01	0.62
Feb	24.29	0.37
Mar	24.27	0.44
Apr	24.73	0.38
May	25.54	0.49
Jun	26.17	0.45
Jul	26.33	0.40
Aug	26.90	0.22
Sep	27.32	0.68
Oct	26.89	0.51
Nov	26.36	0.37
Dec	25.37	0.40
Overall	25.70	0.22

Table 2: *Statistical Estimate of Mean Monthly Temperature at 20m Depth at Kahe HOTS Site (95% Confidence)*

Month	Std Dev [C]	+/- [C]
Jan	0.96	0.52
Feb	0.68	0.29
Mar	0.81	0.35
Apr	0.61	0.31
May	0.79	0.40
Jun	0.73	0.37
Jul	0.71	0.32
Aug	0.38	0.17
Sep	0.99	0.59
Oct	0.86	0.41
Nov	0.60	0.31
Dec	0.64	0.33
Overall	1.17	0.16

Table 3: *Statistical Estimate of Standard Deviation of Monthly Temperature at 20m Depth at Kahe HOTS Site (95% Confidence)*

The confidence intervals are large because there are few data points available. An alternative way of considering the data is to group them by season rather than by month.

Month	Average [C]	Max [C]	Min [C]
Feb-Apr	24.40	25.72	23.28
May-Jul	26.04	27.14	24.85
Aug-Oct	27.00	28.00	25.78
Nov-Jan	25.60	26.99	23.72
Annual	25.70	28.00	23.28

Table 4: *Seasonal Temperatures at 20m Depth at the Kahe HOTS Site*

Month	Mean Temp	+/-
	[C]	[C]
Winter (Feb-Apr)	24.40	0.22
Spring (May-Jul)	26.04	0.26
Summer (Aug-Oct)	27.00	0.23
Fall (Nov-Jan)	25.60	0.33
Annual	25.70	0.22

Table 5: *Statistical Estimate of Mean Seasonal Temperature at 20m Depth at Kahe HOTS Site (95% Confidence)*

Month	Std Dev	+/-
	[C]	[C]
Feb-Apr	0.63	0.16
May-Jul	0.70	0.19
Aug-Oct	0.60	0.17
Nov-Jan	0.85	0.25
Annual	1.17	0.16

Table 6: *Statistical Estimate of Standard Deviation of Seasonal Temperature at 20m Depth at Kahe HOTS Site (95% Confidence)*

Since the confidence intervals are smaller with the seasonal grouping, I recommend we use it until more data is collected.

Statistical Evaluation of Temperatures at 30m

The data at 30m depth is limited just as the data at 20m depth is. Therefore, I recommend we use grouped data.

Month	Average	Max	Min
	[C]	[C]	[C]
Feb-Apr	24.36	25.72	23.14
May-Jul	25.84	27.14	23.78
Aug-Oct	26.90	28.00	25.68
Nov-Jan	25.38	26.99	23.64
Annual	25.56	27.86	23.14

Table 7: *Seasonal Temperatures at 30m Depth at the Kahe HOTS Site*

Estimate of Mean Temperature at 30m		
Month	Mean Temp	+/-
	[C]	[C]
Winter (Feb-Apr)	24.36	0.14
Spring (May-Jul)	25.84	0.19
Summer (Aug-Oct)	26.90	0.14
Fall (Nov-Jan)	25.38	0.28
Annual	25.56	0.19

Table 8: *Statistical Estimate of Mean Seasonal Temperature at 30m Depth at Kahe HOTS Site (95% Confidence)*

Month	Std Dev	+/-
	[C]	[C]
Feb-Apr	0.61	0.10
May-Jul	0.75	0.13
Aug-Oct	0.55	0.10
Nov-Jan	0.84	0.21
Annual	1.17	0.16

Table 9: *Statistical Estimate of Standard Deviation of Seasonal Temperature at 30m Depth at Kahe HOTS Site (95% Confidence)*

Statistical Evaluation of Temperatures at 700m

	Value	+/-
Statistic	[C]	[C]
Mean	5.25	0.03
Std Dev	0.21	0.02

Table 10: *Statistical Estimate of Mean and Standard Deviation of Temperature at 700m Depth at Kahe HOTS Site (95% Confidence)*

Statistical Evaluation of Temperatures at 800m

	Value	+/-
Statistic	[C]	[C]
Mean	4.79	0.02
Std Dev	0.15	0.02

Table 11: *Statistical Estimate of Mean and Standard Deviation of Temperature at 800m Depth at Kahe HOTS Site (95% Confidence)*

Statistical Evaluation of Temperatures at 900m

	Value	+/-
Statistic	[C]	[C]
Mean	4.45	0.02
Std Dev	0.13	0.02

Table 12: *Statistical Estimate of Mean and Standard Deviation of Temperature at 900m Depth at Kahe HOTS Site (95% Confidence)*

Statistical Evaluation of Temperatures at 1000m

	Value	+/-
Statistic	[C]	[C]
Mean	4.11	0.02
Std Dev	0.12	0.01

Table 13: *Statistical Estimate of Mean and Standard Deviation of Temperature at 1000m Depth at Kahe HOTS Site (95% Confidence)*

Recommended Design Temperatures

Mean Temperature

Note that the confidence level on temperature range is 90%. The reduction in confidence is due to the fact that both mean temperature and standard deviation of temperature must be correct for the temperature range to be correct. The reduction was calculated according to the Bonferroni Inequality.

Month	Mean Temp	+/-
	[C]	[C]
Winter (Feb-Apr)	24.40	0.22
Spring (May-Jul)	26.04	0.26
Summer (Aug-Oct)	27.00	0.23
Fall (Nov-Jan)	25.60	0.33
Annual	25.70	0.22

Table 14: *Statistical Estimate of Mean Seasonal Temperature at 20m Depth at Kahe HOTS Site (95% Confidence)*

Month	Mean Temp	+/-
	[C]	[C]
Winter (Feb-Apr)	24.36	0.14
Spring (May-Jul)	25.84	0.19
Summer (Aug-Oct)	26.90	0.14
Fall (Nov-Jan)	25.38	0.28
Annual	25.70	0.22

Table 15: *Statistical Estimate of Mean Seasonal Temperature at 30m Depth at Kahe HOTS Site (95% Confidence)*

	Value	+/-
Statistic	[C]	[C]
Mean	5.25	0.03

Table 16: *Statistical Estimate of Mean Temperature at 700m Depth at Kahe HOTS Site (95% Confidence)*

	Value	+/-
Statistic	[C]	[C]
Mean	4.79	0.02

Table 17: *Statistical Estimate of Mean Temperature at 800m Depth at Kahe HOTS Site (95% Confidence)*

	Value	+/-
Statistic	[C]	[C]
Mean	4.45	0.02

Table 18: *Statistical Estimate of Mean Temperature at 900m Depth at Kahe HOTS Site (95% Confidence)*

	Value	+/-
Statistic	[C]	[C]
Mean	4.11	0.02

Table 19: *Statistical Estimate of Mean Temperature at 1000m Depth at Kahe HOTS Site (95% Confidence)*

Temperature Range

Season	Min Temp	Max Temp
	[C]	[C]
Winter (Feb-Apr)	23.1 +/- 0.4	25.7 +/- 0.4
Spring (May-Jul)	24.6 +/- 0.5	27.4 +/- 0.5
Summer (Aug-Oct)	25.8 +/- 0.4	28.2 +/- 0.4
Fall (Nov-Jan)	23.9 +/- 0.6	27.3 +/- 0.6

Table 20: *Statistical Estimate of Seasonal Temperature Range at 20m Depth at Kahe HOTS Site. Temperature Is Expected to Be in Range 95% of the Time. Confidence Level is 90%.*

Season	Min Temp	Max Temp
	[C]	[C]
Winter (Feb-Apr)	23.1 +/- 0.2	25.6 +/- 0.2
Spring (May-Jul)	24.3 +/- 0.3	27.3 +/- 0.3
Summer (Aug-Oct)	25.8 +/- 0.2	28.0 +/- 0.2
Fall (Nov-Jan)	23.7 +/- 0.5	27.1 +/- 0.5

Table 21: *Statistical Estimate of Seasonal Temperature Range at 30m Depth at Kahe HOTS Site. Temperature Is Expected to Be in Range 95% of the Time. Confidence Level is 90%.*

Min	Max
[C]	[C]
4.83 +/- 0.08	5.66 +/- 0.08

Table 22: *Statistical Estimate of Temperature Range at 700m Depth at Kahe HOTS Site. Temperature Is Expected to Be in Range 95% of the Time. Confidence Level is 90%.*

Min	Max
[C]	[C]
4.49 +/- 0.06	5.10 +/- 0.06

Table 23: *Statistical Estimate of Temperature Range at 800m Depth at Kahe HOTS Site. Temperature Is Expected to Be in Range 95% of the Time. Confidence Level is 90%.*

Min	Max
[C]	[C]
4.19 +/- 0.05	4.71 +/- 0.05

Table 24: *Statistical Estimate of Temperature Range at 900m Depth at Kahe HOTS Site. Temperature Is Expected to Be in Range 95% of the Time. Confidence Level is 90%.*

Min	Max
[C]	[C]
3.86 +/- 0.05	4.35 +/- 0.05

Table 25: *Statistical Estimate of Temperature Range at 1000m Depth at Kahe HOTS Site. Temperature Is Expected to Be in Range 95% of the Time. Confidence Level is 90%.*

Summary Plots

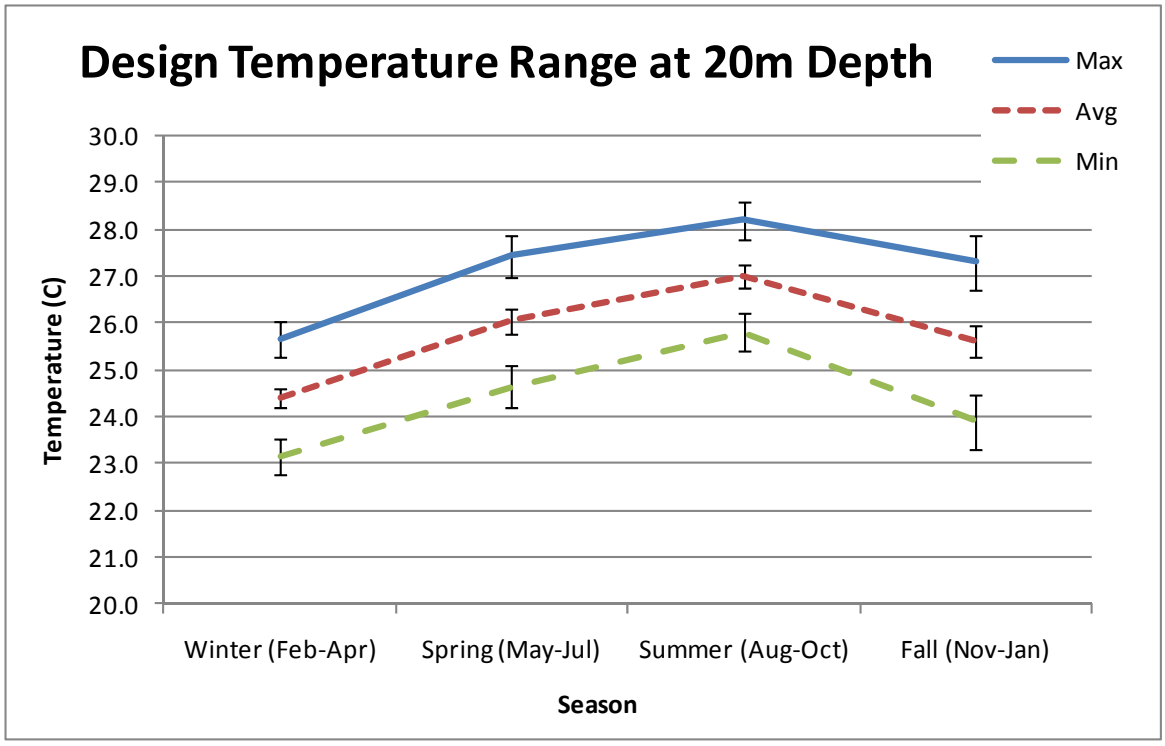


Figure 5: *Statistical Estimate of Design Temperatures at 20m Depth at Kahe HOTS Site (90% Confidence on Max/Min, 95% Confidence on Mean)*

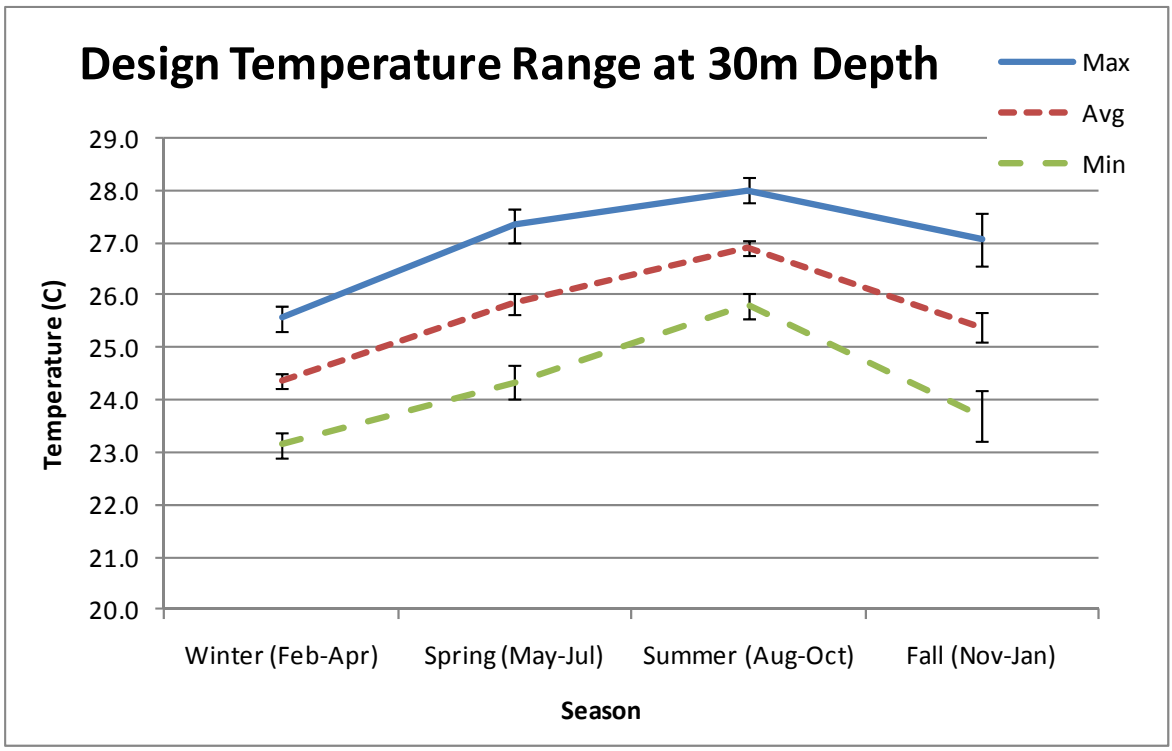


Figure 6: *Statistical Estimate of Design Temperature at 30m Depth at Kahe HOTS Site (90% Confidence on Range, 95% Confidence on Mean)*

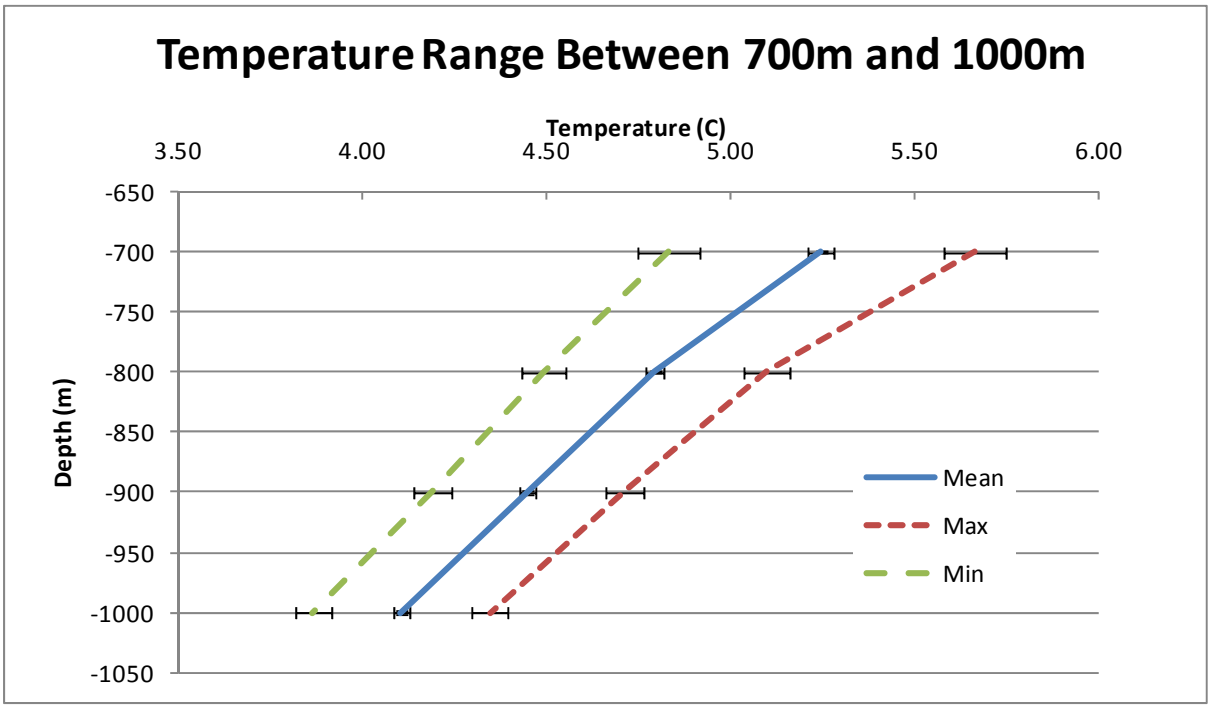


Figure 7: *Statistical Estimate of Design Temperature between 700m Depth and 1000m Depth at Kahe HOTS Site (90% Confidence on Range, 95% Confidence on Mean)*

List of Cruise Dates Used

The following is a list of the dates on which data used in the analysis were collected.

3/24/1953	5/18/1993	3/14/1997	10/17/2000	10/13/2003
12/1/1988	7/26/1993	4/7/1997	11/28/2000	11/8/2003
3/26/1989	9/12/1993	5/5/1997	12/18/2000	12/19/2003
6/23/1989	10/27/1993	6/2/1997	1/15/2001	2/23/2004
7/28/1989	1/18/1994	7/7/1997	2/12/2001	3/19/2004
9/20/1989	2/15/1994	7/31/1997	3/19/2001	4/20/2004
10/17/1989	3/12/1994	9/24/1997	4/16/2001	5/17/2004
1/7/1990	6/17/1994	12/3/1997	5/15/2001	6/14/2004
3/14/1990	8/28/1994	1/9/1998	6/13/2001	7/13/2004
5/7/1990	9/22/1994	2/17/1998	7/10/2001	8/14/2004
7/24/1990	10/13/1994	3/17/1998	8/7/2001	9/27/2004
9/14/1990	11/17/1994	4/14/1998	9/30/2001	10/30/2004
12/16/1990	2/4/1995	5/11/1998	10/21/2001	11/26/2004
2/1/1991	3/2/1995	7/13/1998	11/15/2001	
4/11/1991	4/4/1995	8/8/1998	12/13/2001	
5/5/1991	5/5/1995	9/27/1998	1/14/2002	
6/3/1991	7/29/1995	10/18/1998	2/19/2002	
8/8/1991	8/26/1995	11/9/1998	3/11/2002	
9/16/1991	9/25/1995	12/7/1998	5/23/2002	
10/20/1991	10/30/1995	1/11/1999	6/29/2002	
12/5/1991	11/15/1995	2/16/1999	8/27/2002	
1/4/1992	1/15/1996	3/16/1999	10/5/2002	
2/13/1992	3/25/1996	5/8/1999	11/3/2002	
3/3/1992	4/22/1996	7/12/1999	11/24/2002	
4/16/1992	5/20/1996	8/11/1999	12/17/2002	
6/8/1992	6/24/1996	10/14/1999	1/16/2003	
7/3/1992	7/25/1996	12/14/1999	2/24/2003	
8/3/1992	8/19/1996	2/1/2000	3/28/2003	
9/21/1992	9/30/1996	2/28/2000	4/22/2003	
10/17/1992	10/28/1996	4/24/2000	5/20/2003	
11/23/1992	12/9/1996	6/19/2000	6/18/2003	
1/19/1993	1/6/1997	7/24/2000	7/18/2003	
2/15/1993	2/16/1997	8/21/2000	8/19/2003	

Table 26: *Data Collection Dates*

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-31
Instrument List 12 August 2010
OTEC-2010-001

17 September 2010

Prepared for:

Naval Facilities Engineering Command
Naval Facilities Engineering Service Center (NFESC)
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Port Hueneme, CA 93043-4370
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Prepared by:

Lockheed Martin MS2
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Manassas, VA 20110

Distribution Statement A: Approved for public release; distribution is unlimited

NavFac OTEC Project		Seawater Handling and Ammonia Process Instrument List					12-Aug-10
	NH3 Process Instruments	**Value**	**Location**	**Range**	**Output**	**Controls?**	**Other use**
Buffers							
	L Buff 1a	Level	Remora (wet)	0-100%	4-20 ma	Feed Pump VFD	NH3 inventory, F cal
	L Buff 1b	Level	Remora (wet)	0-100%	4-20 ma	Redundant	NH3 inventory
	L Buff 2a	Level	Remora (wet)	0-100%	4-20 ma	Redundant	NH3 inventory
	L Buff 2b	Level	Remora (wet)	0-100%	4-20 ma	Redundant	NH3 inventory
	T Buff 1 a	Temp	Remora (wet)	0 - 40° C	4-20 ma	pump permissive	Performance calcs
	T Buff 1 b	Temp	Remora (wet)	0 - 40° C	4-20 ma	Redundant	Performance calcs
	T Buff 2 a	Temp	Remora (wet)	0 - 40° C	4-20 ma	Redundant	Performance calcs
	T Buff 2 b	Temp	Remora (wet)	0 - 40° C	4-20 ma	Redundant	Performance calcs
	P Buff 1	Press	Platform	0 - 2000 kPa abs	4-20 ma	no	Performance calcs
	P Buff 2	Press	Platform	0 - 2000 kPa abs	4-20 ma	no	Performance calcs
Condenser							
	T Cond 1 In	Temp	Remora (wet)	0 - 40° C	4-20 ma	no	Performance calcs
	T Cond 1 out	Temp	Remora (wet)	0 - 40° C	4-20 ma	no	Performance calcs
	P Cond 1 In	Press	Remora (wet)	0 - 2000 kPa abs	4-20 ma	no	Performance calcs
	P Cond 1 out	Press	Remora (wet)	0 - 2000 kPa abs	4-20 ma	no	Performance calcs
	T Cond 2 In	Temp	Remora (wet)	0 - 40° C	4-20 ma	no	Performance calcs
	T Cond 2 out	Temp	Remora (wet)	0 - 40° C	4-20 ma	no	Performance calcs
	P Cond 2 In	Press	Remora (wet)	0 - 2000 kPa abs	4-20 ma	no	Performance calcs
	P Cond 2 out	Press	Remora (wet)	0 - 2000 kPa abs	4-20 ma	no	Performance calcs
Feed Pump 1							
	Strainer 1 dP	Press	pod (dry)	0-100 kpa	4-20 ma	alarm if high	Performance calcs
	P Pump 1 in	Press	pod (dry)	0 - 2000 kPa abs	4-20 ma	pump permissive	Performance calcs
	P Pump 1 out	Press	pod (dry)	0 - 2000 kPa abs	4-20 ma	no	Performance calcs
	M pump 1 out	Liq Flow	pod (dry)	0-250 kg/sec	4-20 ma	alarm if low	Performance calcs
	T Pump 1 out	temp	pod (dry)	0 - 40° C	4-20 ma	no	Performance calcs
	Pump 1 VFD	speed	Platform	Hz, Amps, Power	per VFD	Yes	Performance calcs

NavFac OTEC Project		Seawater Handling and Ammonia Process Instrument List					12-Aug-10
	NH3 Process Instruments	**Value**	**Location**	**Range**	**Output**	**Controls?**	**Other use**
Feed Pump 2							
	Strainer 2 dP	Press	pod (dry)	0-100 kpa	4-20 ma	alarm if high	Performance calcs
	P Pump 2 in	Press	pod (dry)	0 - 2000 kPa abs	4-20 ma	pump permissive	Performance calcs
	P Pump 2 out	Press	pod (dry)	0 - 2000 kPa abs	4-20 ma	no	Performance calcs
	M pump 2 out	Liq Flow	pod (dry)	0-250 kg/sec	4-20 ma	alarm if low	Performance calcs
	T Pump 2 out	temp	pod (dry)	0 - 40° C	4-20 ma	no	Performance calcs
	Pump 2 VFD	speed	Platform	Hz, Amps, Power	per VFD	Redundant	Performance calcs
Evap & demister							
	T Evap In	Temp	Remora (wet)	0 - 40° C	4-20 ma	no	Performance calcs
	P Evap in	Press	Remora (wet)	0 - 2000 kPa abs	4-20 ma	no	Performance calcs
	T Evap Out	Temp	Remora (wet)	0 - 40° C	4-20 ma	no	Performance calcs
	P Evap Out	Press	Remora (wet)	0 - 2000 kPa abs	4-20 ma	no	Performance calcs
	P Demis 1	Press	Remora (wet)	0 - 2000 kPa abs	4-20 ma	no	Performance calcs
	T Demis 1	Temp	Remora (wet)	0 - 40° C	4-20 ma	no	Performance calcs
	L Demis 1	Level	Remora (wet)	0-100%	4-20 ma	Recirc valve	no
	P Demis 2	Press	Remora (wet)	0 - 2000 kPa abs	4-20 ma	no	Performance calcs
	T Demis 2	Temp	Remora (wet)	0 - 40° C	4-20 ma	no	Performance calcs
	L Demis 2	Level	Remora (wet)	0-100%	4-20 ma	Recirc valve	no
	M Recirc	Liq Flow	Remora (wet)	0-250 kg/sec	4-20 ma	no	Performance calcs
Pre & Post Turbine Piping							
	M turb in	Gas Flow	Platform	0-250 kg/sec	4-20 ma	Governor	Performance calcs
	P turb in	Press	Platform	0 - 2000 kPa abs	4-20 ma	Governor	Performance calcs
	T turb in	Temp	Platform	0 - 40° C	4-20 ma	Governor	Performance calcs
	P Turb out	Press	Platform	0 - 2000 kPa abs	4-20 ma	Governor	Performance calcs
	T Turb out	Temp	Platform	0 - 40° C	4-20 ma	Governor	Performance calcs
	dP Turb	Press	Platform	0 - 500 kPa	4-20 ma	Governor	Performance calcs
	Turb Trip valve position	% Open	Platform	0-100%	4-20 ma	permissive	no
	M turb Bypass	Gas Flow	Platform	0-250 kg/sec	4-20 ma	Governor	Performance calcs
	M Makeup NH3	Liq Flow	Platform	0-25 kg/sec	4-20 ma	no	NH3 Inventorying

NavFac OTEC Project		Seawater Handling and Ammonia Process Instrument List					12-Aug-10
	NH3 Process Instruments	**Value**	**Location**	**Range**	**Output**	**Controls?**	**Other use**
Instruments on Turbine or Lube Skid							
	Turb Bypass valve position	*% Open*	*TG Skid*	*0-100%*	*4-20 ma*	*Governor*	*Performance calcs*
	Gen freq	*Hz*	*TG Skid*	*55-65 Hz*	*Per Manuf*	*Governor*	*Performance calcs*
	V Gen	*Volts*	*TG Skid*	*Per Manuf*	*Per Manuf*	*permissive*	*Performance calcs*
	Gen Current	*Amps*	*TG Skid*	*Per Manuf*	*Per Manuf*	*Indication*	*Performance calcs*
	Power gen	*kW*	*TG Skid*	*Per Manuf*	*Per Manuf*	*permissive*	*Performance calcs*
	Gen Breaker	*open/close*	*Platform*	*Per Manuf*	*Per Manuf*	*permissive and logic*	*Performance calcs*
	Turb Vibes (at each bearing)	*mils*	*TG Skid*	*Per Manuf*	*Per Manuf*	*permissive*	*no*
	Lube oil Level	*level*	*L/O Skid*	*Per Manuf*	*Per Manuf*	*permissive*	*no*
	Lube oil Pressure	*press*	*L/O Skid*	*Per Manuf*	*Per Manuf*	*permissive*	*no*
	Gen Flame Sensor	*UV*	*TG Skid*	*Per Manuf*	*Per Manuf*	*alarm & trip*	*no*
	Turbine Speed	RPM	*TG Skid*	*Per Manuf*	*Per Manuf*	Alarm	Redundant - Gen Freq
	Seal Oil Buffer Pressure	*Press*	*TG Skid*	*Vac - 2000 kPa*	*Per Manuf*	*Alarm*	*no*
	Other Instruments	**Value**	**Location**	**Range**	**Output**	**Controls?**	**Other use**
	Turb Room vent System		Platform			Alarm if off	no
	P, NH3 tank 1	Pressure	Platform	0-2000 kPa	4-20 ma	none	Safety
	L, NH3 tank 1	Level	Platform	0-100%	4-20 ma	none	Inventory
	P, NH3 tank 2	Pressure	Platform	0-2000 kPa	4-20 ma	none	Safety
	L, NH3 tank 2	Level	Platform	0-100%	4-20 ma	none	Inventory
	P, NH3 tank 3	Pressure	Platform	0-2000 kPa	4-20 ma	none	Safety
	L, NH3 tank 3	Level	Platform	0-100%	4-20 ma	none	Inventory
	P xfr pump in	Pressure	Platform	0-2000 kPa	gauge	none	Safety
	P xfr pump out	Pressure	Platform	0-2000 kPa	gauge	none	Safety

NavFac OTEC Project		Seawater Handling and Ammonia Process Instrument List					12-Aug-10
	Warm Water Instruments	**Value**	**Location**	**Range**	**Output**	**Controls?**	**Other use**
Temperature							
	T WW in 1	Temp	Remora (wet)	0 - 40° C	Per manuf	no	Perform & Predictive maint
	T WW in 2	Temp	Remora (wet)	0 - 40° C	Per manuf	no	Perform & Predictive maint
	T WW in 3	Temp	Remora (wet)	0 - 40° C	Per manuf	no	Perform & Predictive maint
	T WW in 4	Temp	Remora (wet)	0 - 40° C	Per manuf	no	Perform & Predictive maint
	T WW in 5	Temp	Remora (wet)	0 - 40° C	Per manuf	no	Perform & Predictive maint
	T WW in 6	Temp	Remora (wet)	0 - 40° C	Per manuf	no	Perform & Predictive maint
	T WW out 1	Temp	Remora (wet)	0 - 40° C	Per manuf	no	Perform & Predictive maint
	T WW out 2	Temp	Remora (wet)	0 - 40° C	Per manuf	no	Perform & Predictive maint
	T WW out 3	Temp	Remora (wet)	0 - 40° C	Per manuf	no	Perform & Predictive maint
	T WW out 4	Temp	Remora (wet)	0 - 40° C	Per manuf	no	Perform & Predictive maint
	T WW out 5	Temp	Remora (wet)	0 - 40° C	Per manuf	no	Perform & Predictive maint
	T WW out 6	Temp	Remora (wet)	0 - 40° C	Per manuf	no	Perform & Predictive maint
Pumping							
	M WW 1	Flow	Remora (wet)	0 - 30 Te/sec	4-20 ma	no	Performance calcs
	M WW 2	Flow	Remora (wet)	0 - 30 Te/sec	4-20 ma	redundant	Performance calcs
	dP WW evap inlet and outlet	Press	Remora (wet)	0-100 kPa	4-20 ma	alarm if High	Performance calcs, clogging
	dP WW Intake Screen	Press	Remora (wet)	0-100 kPa	4-20 ma	alarm if High	Performance calcs, clogging
	dP WW pump inlet to discharge	Press	Remora (wet)	0-100 kPa	4-20 ma	alarm if High	Performance calcs
	WW Pump VFD	speed	Platform	Hz, Amps, Power	per VFD	During startup	Performance calcs
	WW Pump Current	Amps	Platform	per manuf	per manuf	permissive	Performance calcs
	WW Pump Temperature	temp	Remora (wet)	per manuf	per manuf	permissive	Predictive maintenance
	WW Pump Vibes	mils	Remora (wet)	per manuf	per manuf	permissive	Predictive maintenance
	WW Pump Seal oil Press	Press	Platform	per manuf	per manuf	permissive	Predictive maintenance
	WW Inlet camera	Optical	Remora (wet)	Optical	NTSC	no	Predictive maintenance
	WW Inlet NH3 Sensor	ppm	Platform	tbd	Per manuf	alarm if high	Predictive maintenance
	WW Disch NH3 Sensor	ppm	Remora (wet)	tbd	Per manuf	alarm if high	Predictive maintenance
	WW Disch Clorine Sensor	ppb	Remora (wet)	0-10,000 ppb	Per manuf	alarm if high	Scheduled maintenance
	WW Chlorine System	Different System				Schedule or As needed per WW dT calcs	

NavFac OTEC Project		Seawater Handling and Ammonia Process Instrument List					12-Aug-10
	Cold Water Instruments	**Value**	**Location**	**Range**	**Output**	**Controls?**	**Other use**
Temperature							
	T CW in 1	Temp	Remora (wet)	0 - 40° C	Per manuf	no	Perform & Predictive maint
	T CW in 2	Temp	Remora (wet)	0 - 40° C	Per manuf	no	Perform & Predictive maint
	T CW out 1	Temp	Remora (wet)	0 - 40° C	Per manuf	no	Perform & Predictive maint
	T CW out 2	Temp	Remora (wet)	0 - 40° C	Per manuf	no	Perform & Predictive maint
Pumping							
	M CW 1	Flow	Remora (wet)	0 - 25 Te/sec	4-20 ma	no	Performance calcs
	M CW 2	Flow	Remora (wet)	0 - 25 Te/sec	4-20 ma	redundant	Performance calcs
	CW Pump VFD	speed	Platform	Hz, Amps, Power	per VFD	During startup	Performance calcs
	CW Pump Current	Amps	Platform	per manuf	per manuf	permissive	Performance calcs
	CW Pump Temperature	temp	Remora (wet)	per manuf	per manuf	permissive	Predictive maintenance
	CW Pump Vibes	mils	Remora (wet)	per manuf	per manuf	permissive	Predictive maintenance
	CW Pump Seal oil Press	Press	Platform	per manuf	per manuf	permissive	Predictive maintenance
	CW Inlet camera	Optical	Remora (wet)	Optical	NTSC	no	Predictive maintenance
	CW Inlet NH3 Sensor	ppm	Platform	tbd	Per manuf	alarm if high	Predictive maintenance
	CW Disch NH3 Sensor	ppm	Remora (wet)	tbd	Per manuf	alarm if high	Predictive maintenance
	CW Disch Clorine Sensor	ppb	Remora (wet)	0-10,000 ppb	Per manuf	alarm if high	Scheduled maintenance
	CW Chlorine System	Different System				Use based upon CW dT measurements	
	dP CW Cond inlet and outlet	Press	Remora (wet)	0-100 kPa	4-20 ma	alarm if High	Performance calcs, clogging
	dP CW Termination to Elbow	Press	Remora (wet)	0-100 kPa	4-20 ma	alarm if High	Performance calcs, clogging
	dP CW pump inlet to discharge	Press	Remora (wet)	0-100 kPa	4-20 ma	alarm if High	Performance calcs
	CW pump inlet Press	Press	Remora (wet)	400-900 kPa	4-20 ma	alarm if low	For heave-induced variation

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-32
Condenser Appendix A
OTEC-2010-001

17 September 2010

Prepared for:

Naval Facilities Engineering Command
Naval Facilities Engineering Service Center (NFESC)
1100 23rd Avenue
Port Hueneme, CA 93043-4370
Attn: Mr. Brian Cable, Contracting Officer Representative

Prepared by:

Lockheed Martin MS2
9500 Godwin Drive
Manassas, VA 20110

Distribution Statement A: Approved for public release; distribution is unlimited

APPENDIX Condenser A

Datasheet of Alternate Condenser Design Using Spirally Indented Enhanced Tubes

HEAT EXCHANGER SPECIFICATION SHEET Page 1

Prepared by E3Tec Service, LLC SI Units

					Job No.				
Customer					Reference No.				
Address					Proposal No.				
Plant Location	Hawaii				Date	7/28/2010		Rev	2
Service of Unit	Ammonia Condenser				Item No.				
Size	4100 x 7000 mm	Type	AEL	Vert. Connected In		2 Parallel		1 Series	
Surf/Unit	20953 m2	Shell/Unit	2	Surf/Shell	10476 m2				

PERFORMANCE OF ONE UNIT

Fluid Allocation		Shell Side		Tube Side	
Fluid Name					
Fluid Quantity, Total	kg/s	212.00		18,330.00	
Vapor (In/Out)		203.50			
Liquid		8.50	212.00	18,330.0	18,330.00
Steam					
Water					
Noncondensables					
Temperature (In/Out)	C	9.57	9.51	4.10	7.88
Density	kg/m3		0.6248	1028	1028
Viscosity	cp	0.01	0.166	1.63	1.63
Molecular Weight, Vapor					
Molecular Weight, Noncondensables					
Specific Heat	kJ/kg-C	2.41	4.68	4.00	4.20
Thermal Conductivity	W/m-C	0.024	0.525	0.57	0.57
Latent Heat	kJ/kg	1235.7	1235.9		
Inlet Pressure	kPa	607.80			
Velocity	m/s	1.02		1.52	
Pressure Drop, Allow/Calc	kPa	5.00	1.31	25.0	28.4
Fouling Resistance (min)	m2-K/W			0.0090	

Heat Exchanged MW	241	MTD (Corrected)	3.52 C		
Transfer Rate, Service	3260 W/m2-K	Clean	3360 W/m2-K	Actual	3260 W/m2-K

CONSTRUCTION OF ONE SHELL

			Shell Side	Tube Side
Design/Test Pressure		kPaG	1167 / Full Vacuum + 4 bar external pressure	1167 External pressure/Full Vacuum
Design Temperature		C	-28	-28
No Passes per Shell			1	1
Corrosion Allowance		mm		
Connections	In	mm	1 @ 1500.00 with vapor distributor	Buyer to specify
Size &	Out	mm	1 @ 1200.00@ 400 to 500 mm	Buyer to specify
Rating	Intermediate		@	@

Sketch (Enhanced Tube)



Tube No.	34388	OD	15.875 mm	Thk(Avg)	0.559 mm	Length 7.0 m	Pitch 19.8 mm Layout 60
Tube Type	Twisted					Material	TITANIUM-GRADE 2
Shell	ID	4100	od	4170	mm	Shell Cover	
Channel or Bonnet						Channel Cover	
Tubesheet-Stationary						Tubesheet-Floating	
Floating Head Cover						Impingement Plate	None

Baffles-Cross	Type Rod Baffles	%Cut (Diam)		Spacing(c/c)	Inlet mm
Baffles-Long		Seal Type			
Supports-Tube		U-Bend		Type	
Bypass Seal Arrangement		Tube-Tubesheet Joint			
Expansion Joint		Type			
Rho-V2-Inlet Nozzle	kg/m-s2	Bundle Entrance		Bundle Exit	kg/m-s2
Gaskets-Shell Side		Tube Side			
-Floating Head					
Code Requirements				TEMA Class	
				Bundle 71202	kg

Remarks:

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-33
SW Duct Sizing
OTEC-2010-001

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Prepared for:

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Naval Facilities Engineering Service Center (NFESC)
1100 23rd Avenue
Port Hueneme, CA 93043-4370
Attn: Mr. Brian Cable, Contracting Officer Representative

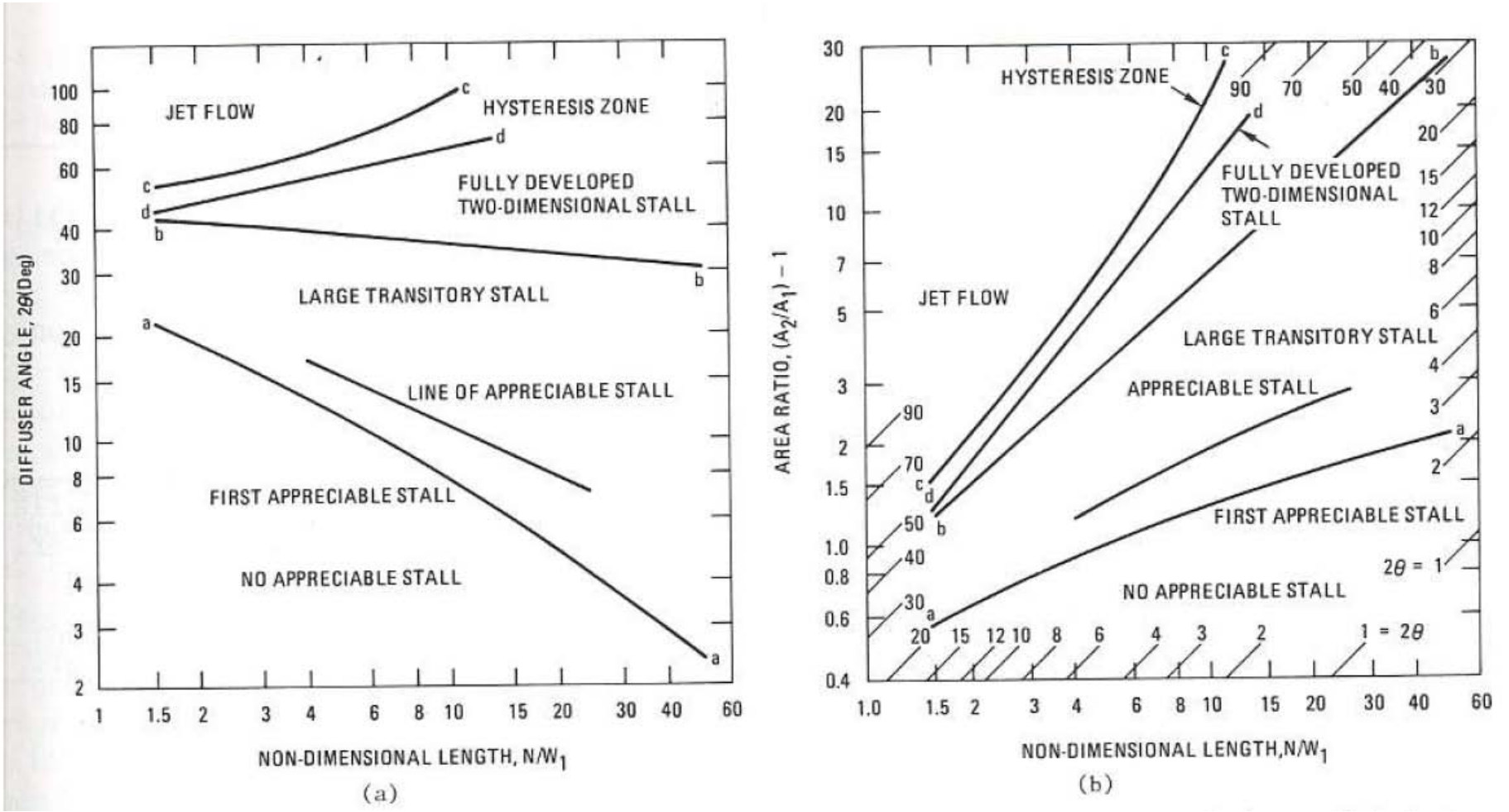
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APPENDIX 3.3.2.1.1-19

Remora Iteration 2.1—Crossover Cold Water Pipe & Cold and Warm Water Diffuser Sizing



From: Blevins, Applied Fluid Dynamics Handbook, Van Norstrand Reinhold Company, 1984

CW Crossover Pipe									
		Din	2.84		Ain	6.334707			
		Dout	3.175		Aout	7.917304			
N (m)	L (m)	y (m)	Θ (deg)	2Θ (deg)	N/W1		A2/A1-1		
5	47.388	0.1675	1.918691	3.837382	1.760563		0.24983		0.20252
10	94.776	0.1675	0.959615	1.919229	3.521127		0.24983		0.10126
12	113.731	0.1675	0.799702	1.599403	4.225352		0.24983		0.084384
15	142.164	0.1675	0.639776	1.279553	5.28169		0.24983		0.067507
20	189.552	0.1675	0.479841	0.959682	7.042254		0.24983		0.05063

Bottom Pipe							
Cold		Din	2.84		Ain	6.334707	
		Dout	3.26		Aout	8.346898	
N (m)	L (m)	y (m)	Θ (deg)	2Θ (deg)	N/W1		A2/A1-1
10		0.21	1.203035	2.406069	3.5		0.317645
11		0.21	1.093696	2.187391	3.9		0.317645
12		0.21	1.002574	2.005148	4.2		0.317645
4.67		0.21	2.574735	5.14947	1.6		0.317645
20		0.21	0.601584	1.203167	7.0		0.317645
Warm		Din	2.55		Ain	5.107052	
		Dout	4.53		Aout	16.11708	
N (m)	L (m)	y (m)	Θ (deg)	2Θ (deg)	N/W1		A2/A1-1
10		0.99	5.653859	11.30772	3.9		0.317645
11		0.99	5.142765	10.28553	4.3		0.317645
12		0.99	4.716221	9.432442	4.7		0.317645
15		0.99	3.776045	7.55209	5.9		0.317645
20		0.99	2.833828	5.667656	7.8		0.317645
		Din	2.5		Ain	4.908739	
		Dout	4.4		Aout	15.20531	
N (m)	L (m)	y (m)	Θ (deg)	2Θ (deg)	N/W1		A2/A1-1
10		0.95	5.426812	10.85362	4.0		0.317645
11		0.95	4.936024	9.872048	4.4		0.317645
12		0.95	4.526475	9.052951	4.8		0.317645
15		0.95	3.623893	7.247785	6.0		0.317645
20		0.95	2.719505	5.439011	8.0		0.317645
		Din	2.5		Ain	4.908739	
		Dout	4.2		Aout	13.85442	
N (m)	L (m)	y (m)	Θ (deg)	2Θ (deg)	N/W1		A2/A1-1
10		0.85	4.858463	9.716926	4.0		0.317645
11		0.85	4.41862	8.837241	4.4		0.317645
12		0.85	4.051684	8.103368	4.8		0.317645
15		0.85	3.243292	6.486585	6.0		0.317645
20		0.85	2.433606	4.867212	8.0		0.317645

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-34
Condenser Appendix B
OTEC-2010-001

17 September 2010

Prepared for:

Naval Facilities Engineering Command
Naval Facilities Engineering Service Center (NFESC)
1100 23rd Avenue
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Manassas, VA 20110

Distribution Statement A: Approved for public release; distribution is unlimited

APPENDIX Condenser B

Condenser Design Schematic Diagrams

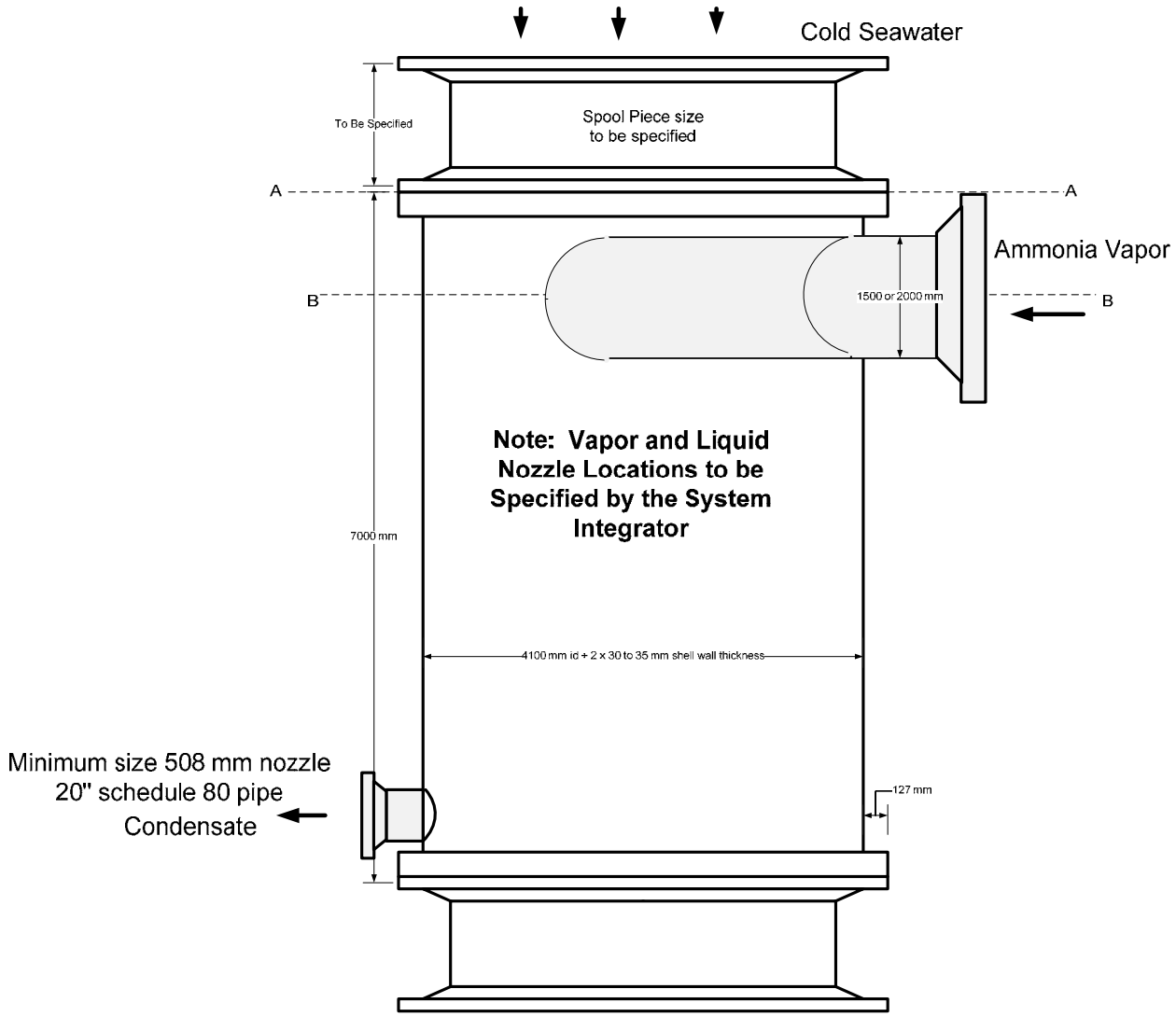


Figure B.1 Schematic of Condenser (one of two units)

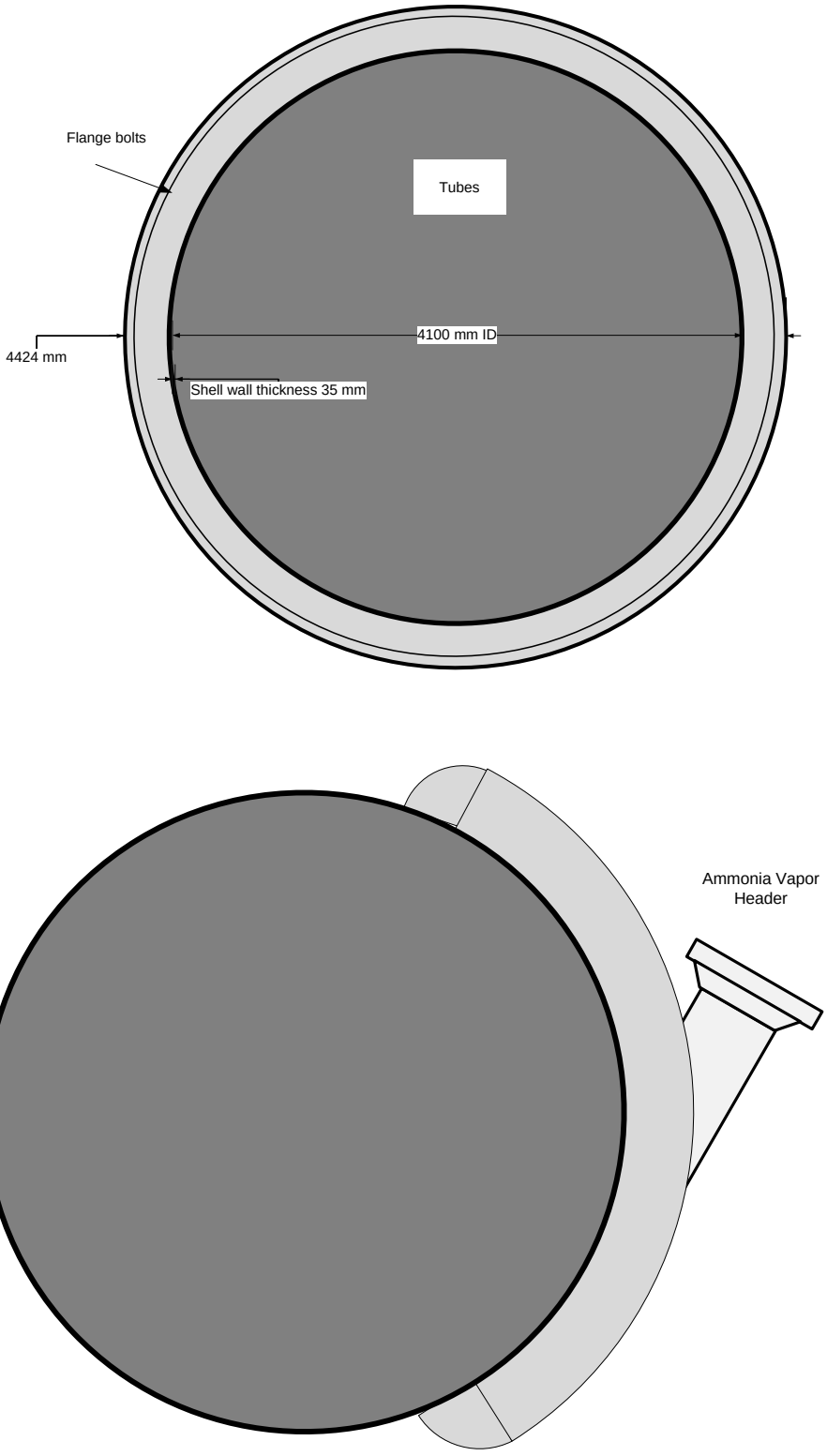
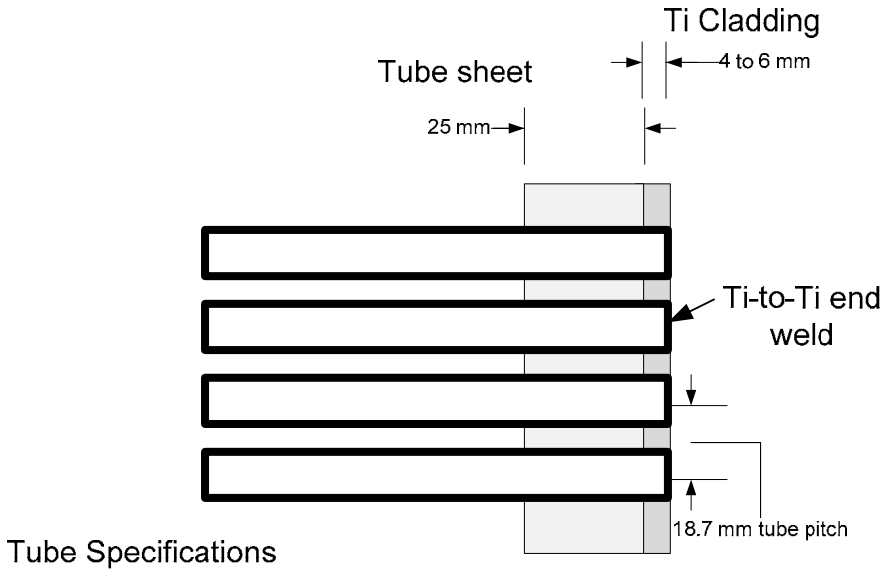


Figure B.2 Cross-Sections A-A and B-B



Tube Specifications
OD 15.875 mm
Wall Thickness 0.559 mm
Length 7000 mm
Tube Type – Twisted or Spirally Indented

Figure B.3 Details of Tube to Tube-Sheet Joints

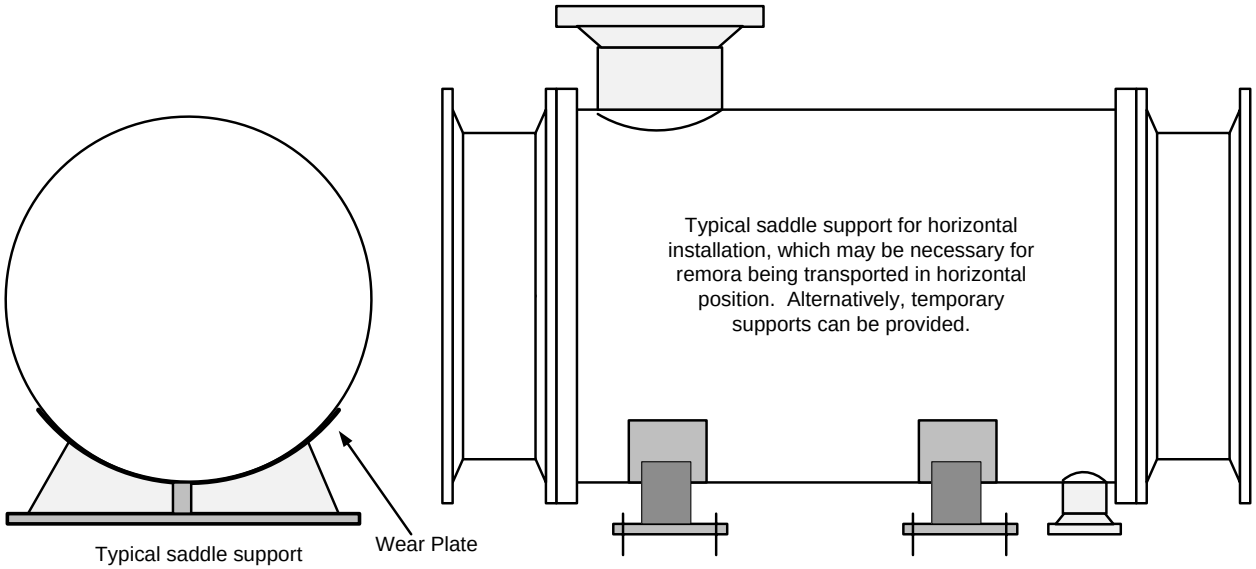


Figure B.4 Conventional Saddle Supports for Horizontal Installation

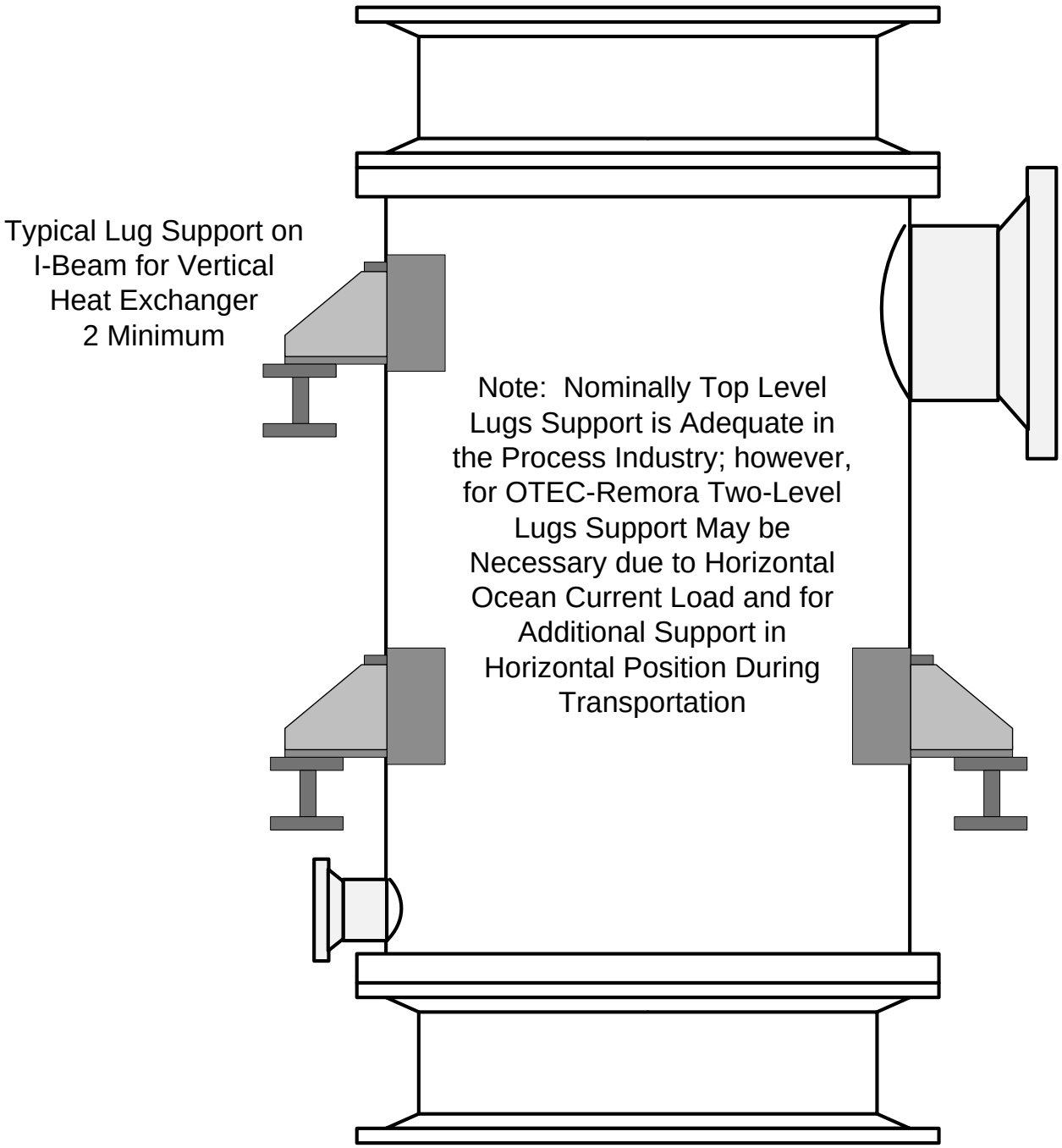


Figure B.4 Conventional Lug Supports for Vertical Installation

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-35
CFD Study
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1100 23rd Avenue
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Distribution Statement A: Approved for public release; distribution is unlimited

APPENDIX 3.3.2.1.1-20

Remora Iteration 2.1—Cold Water Piping
Computational Fluid Dynamics (CFD) Study

Remora Iteration 2.1

CWP Surface Roughness Study

Rachel Lipanovich, Makai Engineering

6 April 2010

MAKAI OCEAN ENGINEERING, INC.
P0 Box 1206, Kailua, Hawaii 96734 - USA
(808) 259-8871 FAX: (808) 259-8238

April 6, 2010

MEMO

TO: OTEC Team
Company:
Address:

From: Rachel Lipanovich

Subject: CWP Roughness Contract: OTEC - 15706

Introduction:

In order to calculate the hydraulic losses in the OTEC CWP, the pipe roughness must be determined. This memo presents the method used to calculate the roughness and the resulting roughness value.

Theory:

The Darcy-Weisbach method is commonly used to determine flow losses. It is presented in Equation 1.

$$h_f = f \frac{L}{D} \frac{V^2}{2g}$$

Equation 1: Darcy-Weisbach Equation

h_f = *friction loss (ft)*
f = *friction factor*
L = *pipe length (ft)*
D = *pipe inner diameter (ft)*
V = *velocity (ft/s)*
g = *gravitational constant (ft/s^2)*

The friction factor, f, has typically been determined experimentally by measuring the head loss under various conditions. It can also be calculated by using Equation 2.

$$\frac{1}{\sqrt{f}} = -2 \log_{10} \left(\frac{e}{3.7D} + \frac{2.51}{R\sqrt{f}} \right)$$

Equation 2: Colebrook formula for friction factor

e = *absolute roughness (ft)*
R = *Reynolds Number*

The roughness of standard pipe materials have been well documented, but new pipe materials are typically tested to experimentally determine the appropriate roughness to use in the above equation. For the OTEC fiberglass pipe, the best we can do at the moment is determine

the roughness by looking at the pipe profile. This number can be verified experimentally at a later time. The arithmetic average roughness of the profile can be substituted for e in Equation 2. Arithmetic average roughness is defined by Equation 3 and illustrated in Figure 1. It is the average distance the surface varies from the mean value.

$$R_a = \frac{1}{n}\sum_{i=1}^{n}|y_i|$$

Equation 3: **Equation for the arithmetic average roughness**

R_a = *arithmetic average roughness*
n = *number of elements*
i = *iterator*
y_i = *distance from the mean*

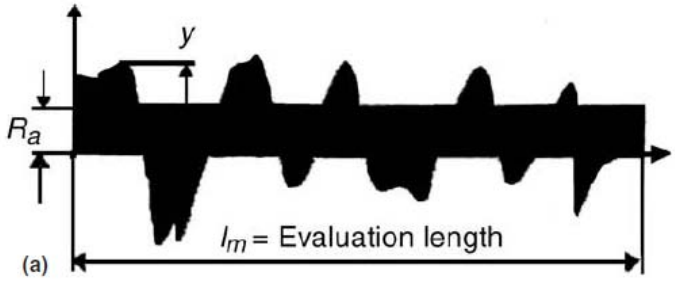


Figure 1: **Illustration of arithmetic average roughness**

Method:

Calculating the roughness involves two parts:

1. Converting a piece of pipe to a digital profile.
2. Appling Equation 3 to the resulting profile.

This first step was approached by taking several sections of pipe and scanning the cross section at 600 dpi to create a digital image. Next, each image was processed using Adobe Photoshop. The images were converted to grayscale, where 0=black and 255=white. They were also straightened based on the flat bottom of the scanned section. The edge of the top of the pipe needs to be clearly defined, so the dark background was selected using a tolerance of 20. Tolerance ranges from 0-255 and determines which colors are selected, where 0 is more finely tuned. A setting of 20 was used after some experimentation showed it resulted in a surface that most closely matched the line that would be drawn by hand. The background was then made completely black (0). An example of one of these images before and after processing is shown in Figure 2. This was done for 10 sections of pipe, each roughly 7” long.

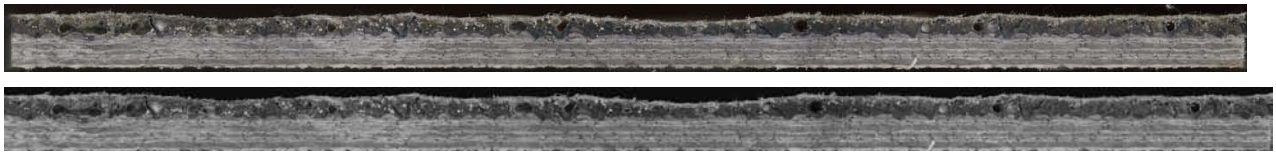


Figure 2: **Scanned image of a pipe section before (top) and after (bottom) image processing.**

The rest of the image processing was done with a Matlab program. The program converts the image file to a matrix, with each position in the matrix corresponding to a pixel in the picture, and having a value between 0 and 255. Next, the program starts at the top and goes down each column. It interrogates the value/pixel in each row to see if it is larger/lighter than a threshold value. When it reaches a row that is large/light enough, then that point is considered the surface of the pipe. The position of that row is saved in a vector and the program moves to the next column. The result is a vector of the distances to the pipe surface at every pixel moving left to right across the pipe. The vector is recording the amount of black above the pipe rather than the pipe thickness, but this is irrelevant to the roughness calculations. The profile for Figure 2 is shown in Figure 3.

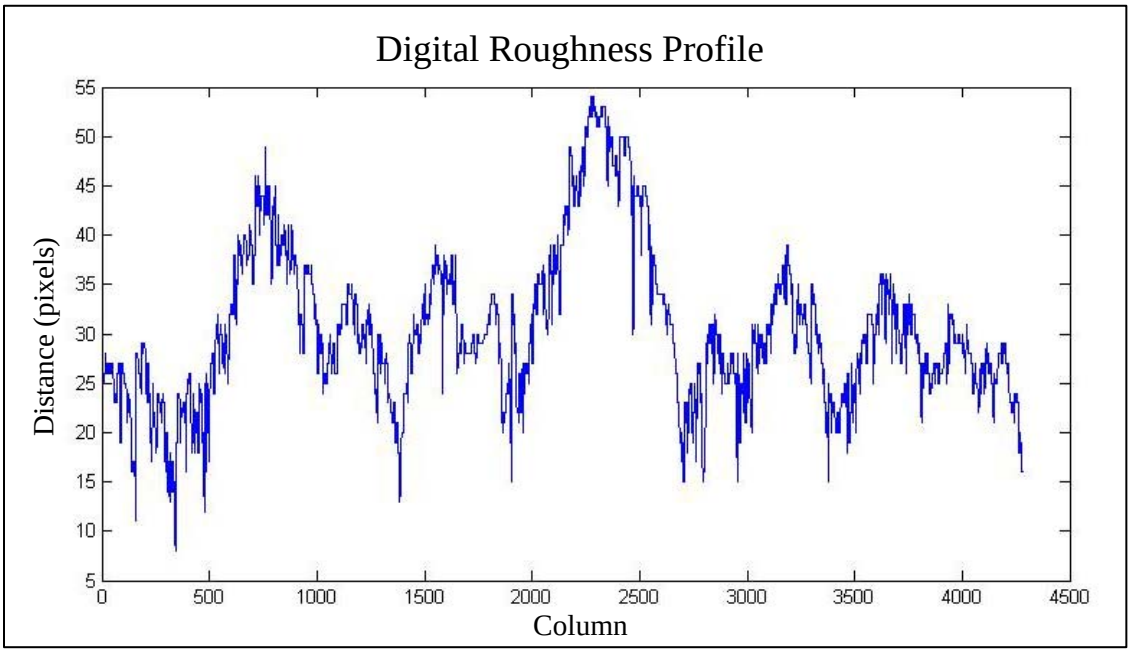


Figure 3: **Pipe profile determined by Matlab**

Once the digital profile has been created, the program uses Equation 3 to calculate the roughness.

Results:

The resulting roughness of each of the 10 pipe sections is presented in Table 1. The OTEC CWP roughness is shown along with the roughness of standard pipe materials in Table 2.

Pipe Section	Ra (pixels)	Ra (µm)
1	6.085	258
2	6.876	291
3	9.084	385
4	7.963	337
5	7.122	301
6	10.079	427
7	7.9359	336
8	9.4505	400
9	9.8509	417
10	8.3758	355
Average	8.282	351
Std Dev	1.337	57

Table 1: OTEC fiberglass pipe roughness

Material	Roughness (µm)
drawn copper	1.5
steel	45
cast iron	260
concrete	300-3000
OTEC fiberglass	351

Table 2: Comparison of the roughness of OTEC fiberglass with other pipe materials

The average roughness was calculated to be 351 microns. While the standard deviation is a relatively large 57 microns, notice that this is only slightly more than one pixel and therefore at the limit of our current capabilities. A roughness of 351 microns can be used to determine the hydraulic losses in the pipe, or a standard deviation can be added to be more conservative if that is thought necessary. Future calculations or experiments could be done to refine this number in the future.

References:

Farshad, Fred F., and H. H. Rieke. "Technology Innovation for Determining Surface Roughness in Pipes." *Journal of Petroleum Technology* October (2005): 82-86. Web. <http://www.spe.org/jpt/print/archives/2005/10/JPT2005_10_tech_todayseries.pdf>.

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Remora Iteration 2.1

Cold Water Piping System

CFD Study

Mealani Parish, Navatek, Ltd

OTEC Cold Water Assembly: CFX Status Update

29 April 2010

Prepared by: M. Parish, Navatek, Ltd.

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Part 1 Straight Pipe Flow: Objectives & Problem Set-up

Objective:

- Determine mesh settings and CFD solver settings required to model internal flow at the conditions provided
  - Determine mesh density required to simulate pressure drop and velocity profile
  - Determine length required to obtain a fully-developed velocity profile
  - Establish method of defining velocity at inlet

Flow Conditions Provided:

- Water at 40 degF flows through a pipe with diameter 4 m at a flow rate of 17.8 m^3/s. Assume the internal pipe surface is new steel.

Problem Set-up:

- To simplify the problem, a straight, circular pipe was first modeled, and it was assumed that buoyancy and heat transfer were not significant factors.
- The flow was assumed to be fully turbulent given the Reynolds number calculated.
- The length of pipe to model was chosen to be 300 m, significantly longer than the predicted entrance length.

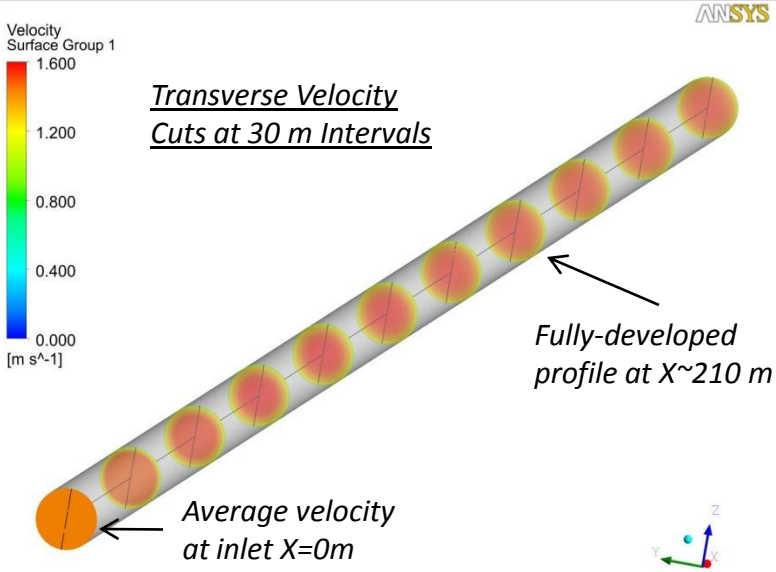
OTEC CFX Settings		
Geometry	Type	Straight circular pipe
	Diameter	4.00 m
	Length	300.00 m
Flow Properties	Fluid temperature	40 degF
	Fluid density	1027.742 kg/m^3
	Fluid kinematic viscosity	1.59e-6 m^2/s
	Volumetric flow rate	17.8 m^3/s
	Mass flow rate	18,294 kg/s
	Average velocity	1.416 m/s
	Reynolds number	3.564e+6
	Entrance length	218 m
	Surface roughness	6.00e-5 m
	Friction factor	0.01
CFD Solver	Software	ANSYS CFX v12
	Steady or unsteady	Steady
	Homogeneity	Homogeneous
	Turbulence model	SST, fully turbulent
	Buoyancy	None
	Heat transfer	None

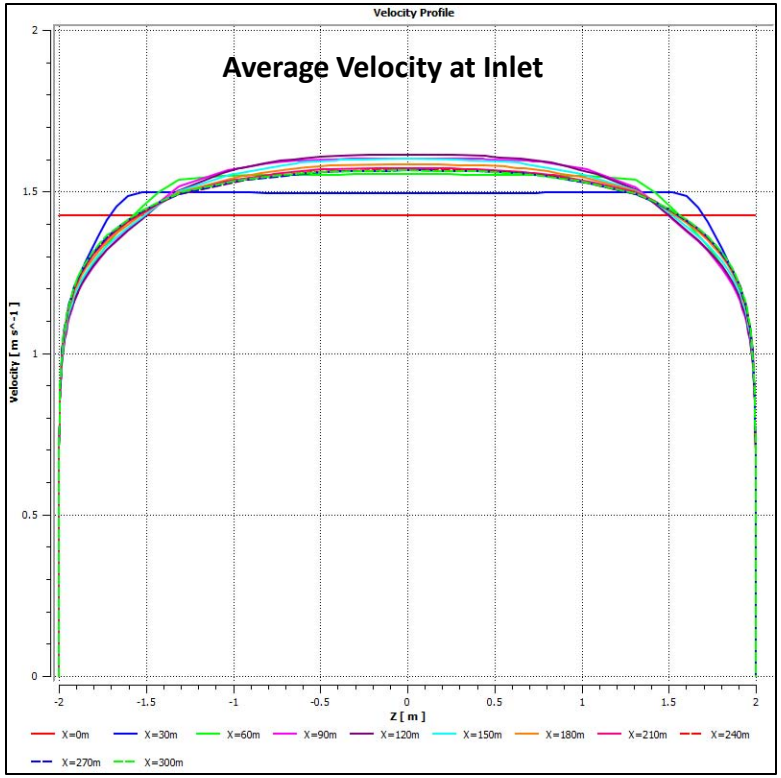
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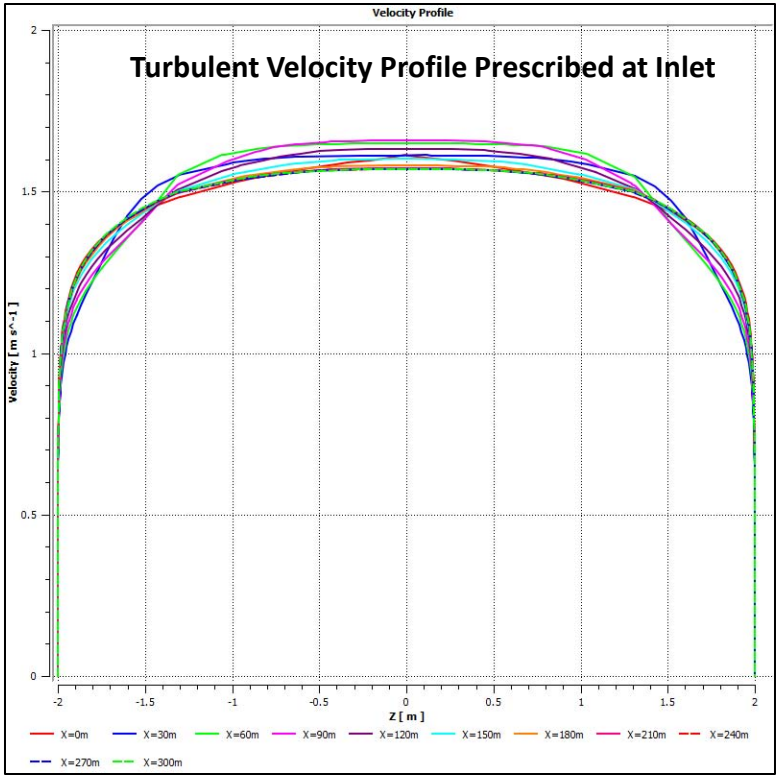
Part 1 Straight Pipe Flow: Results

Velocity Profile & Entrance Length:

- Two different velocity profiles were set at the inlet:
  - Average velocity (constant velocity across the pipe diameter)
  - Prescribed velocity (theoretical fully-turbulent velocity profile)
- The pipe length required for the velocity profile to stabilize was approximately equal to the theoretical entrance length of 218 m.
- The entrance length did not seem to be affected by the type of velocity profile at the inlet. An average velocity at the inlet was selected for future runs to get a more accurate definition of the mass flow rate (and volume flow rate) entering the pipe.







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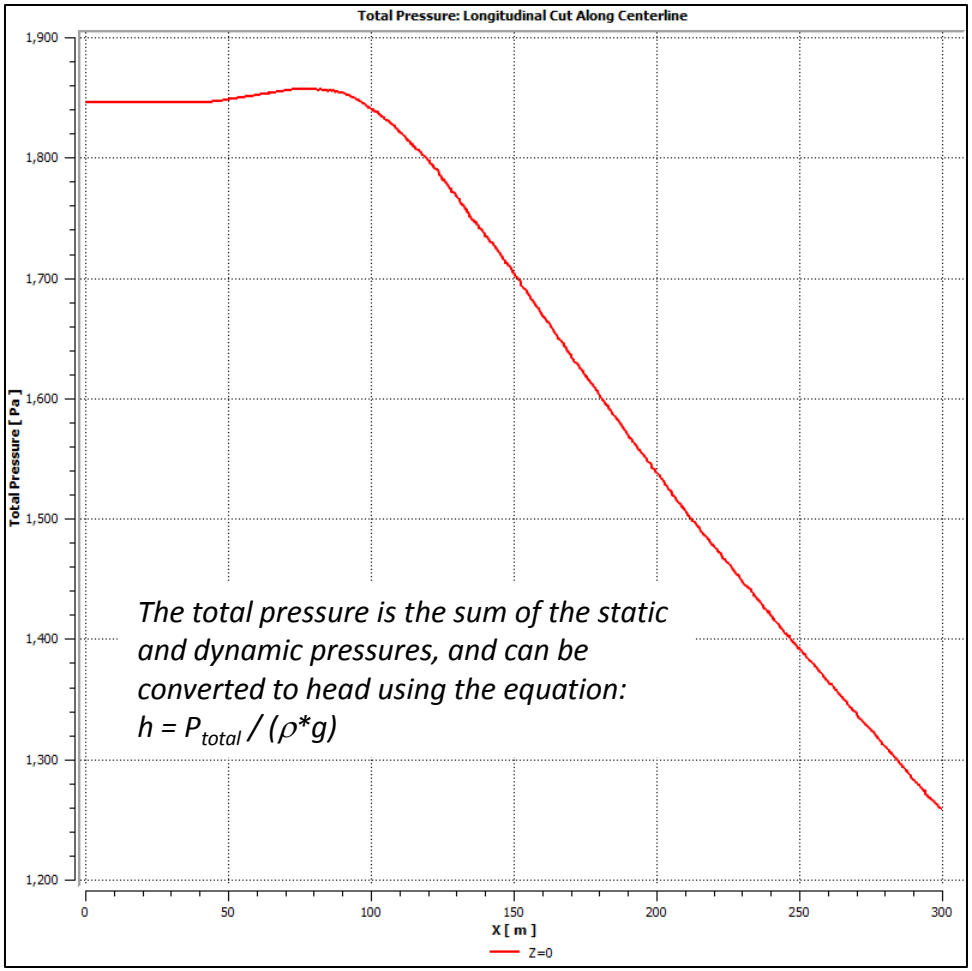
Pressure Drop & Mesh Settings:

- The drop in total pressure over 50 m (in an area where the flow was assumed to be fully-developed) was extracted from the results and plotted against various mesh properties.
- The inflated boundary and mesh spacing required was thus determined.
- Note: The pressure drop for flow in straight pipes is a measure of the frictional losses and can be converted to head losses using $h = P_{total} / (\rho * g)$.
- The pressure drop calculated in CFX was 3-5% above the theoretical pressure drop calculated using the Darcy equation:

  $h_f = (f * L * v_{avg}^2)/(2 * D * g)$

  where *f* is the friction factor obtained from Moody diagrams.

Total Pressure vs Distance Along X-Axis



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Summary:

- The mesh Settings were determined for future runs:
  - Inflated boundary settings, transverse and longitudinal mesh spacings
  - Length > ~210 m for lead-in duct (unless a more sophisticated method of initializing each run is found)
- Solver settings were determined for future runs:
  - Turbulence model
  - Inlet settings
- CFX predicted a pressure drop ~5% greater than the theoretical pressure drop predicted by hand calculations.

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Part 2 Cross-Connect Duct: Objectives & Problem Set-up

PRELIMINARY RESULTS ONLY

Objectives:

- Before the remainder of the CW (Cold Water) assembly was modeled, the cross-connect duct was added to the 4 m straight lead-in duct to gain more experience with the model and results when a bend is introduced (e.g., areas of flow separation, mesh density at bends).

Problem Set-up:

- Lead-in Duct:
  - Diameter 4 m
  - Length 40 m (not adequate for fully-developed flow, but acceptable for the purposes of this problem)
- Cross-Connect Duct:
  - "Tight Radius" design
  - Diameter approximately 2.83 m
- Volume flow rate 16.5 m^3/s per half of lead-in duct
- A symmetry plane was used to model the other half of the CW assembly
- All other flow and solver settings were similar to those used for the straight duct.

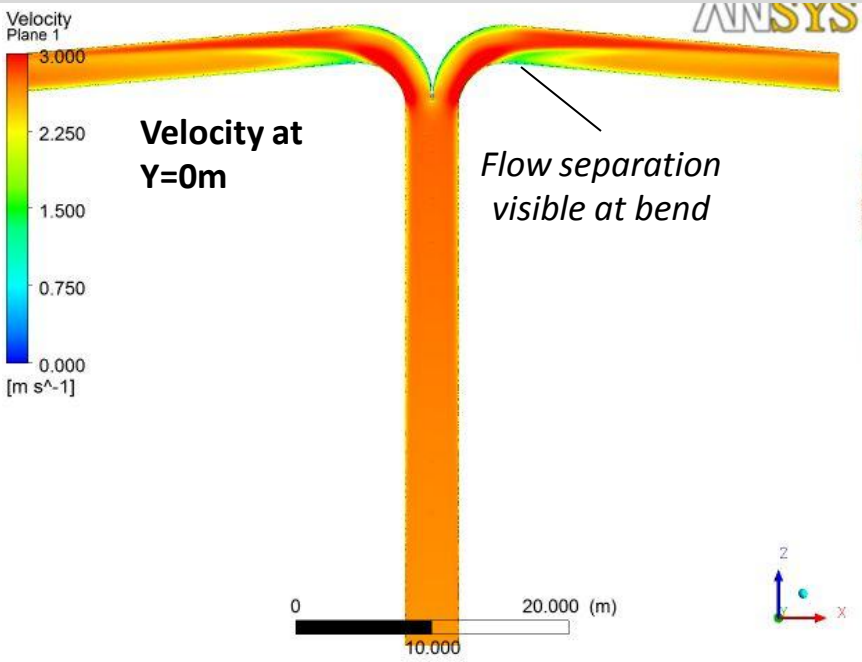
Summary:

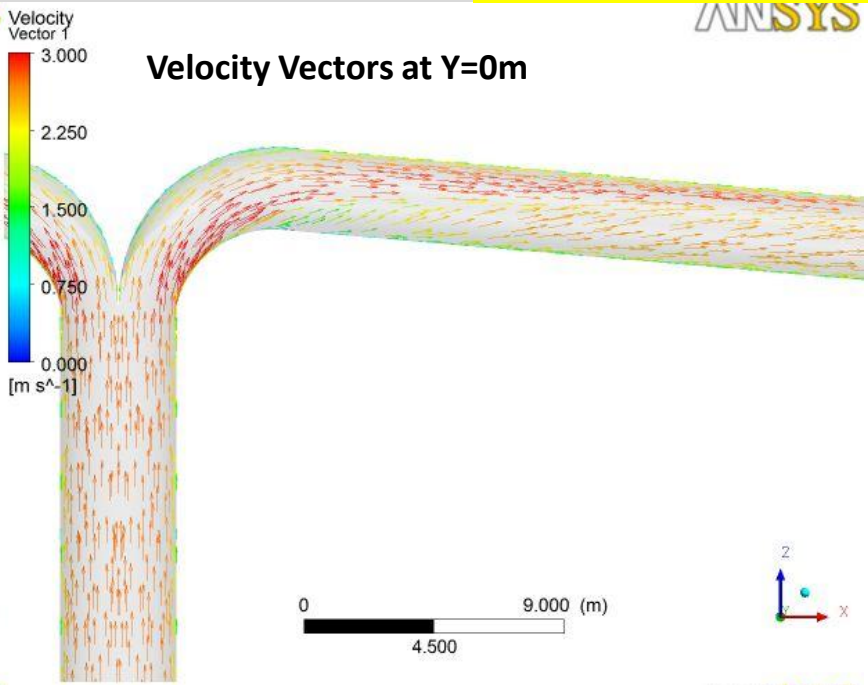
- Flow separation at the pipe bend could be visualized in the CFX results.

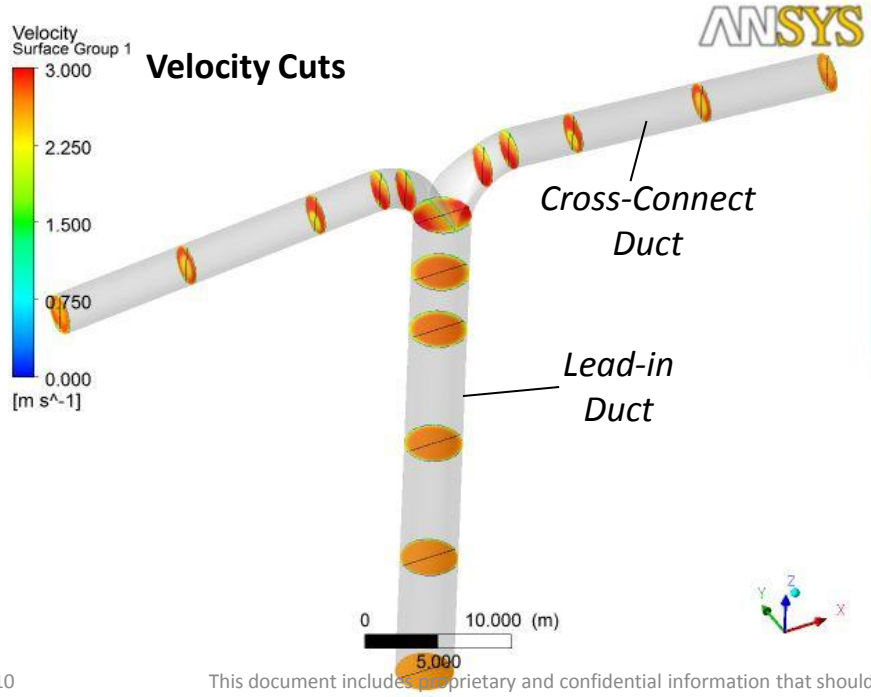
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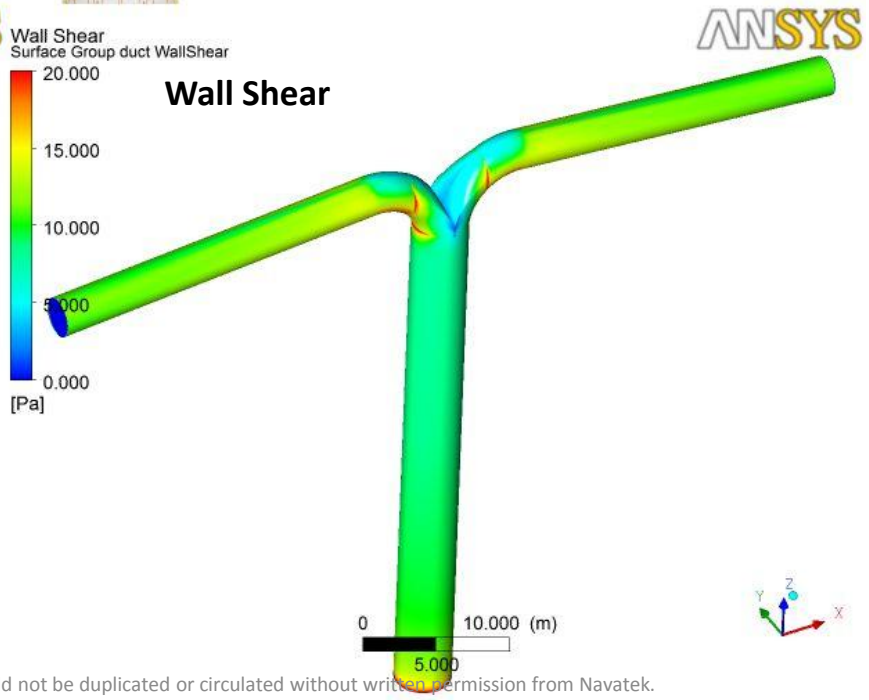
Part 2 Cross-Connect Duct: Sample Results

PRELIMINARY RESULTS ONLY









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Part 3 OTEC CW Assembly: Objectives & Problem Set-up

PRELIMINARY RESULTS ONLY

Objectives:

- Visualize flow into heat exchangers
  - Design objective: obtain uniform flow into heat exchangers (i.e., avoid having non-working areas of the heat exchanger)
- Measure head losses
  - Design objective: minimize head losses
- Determine a simple method to simulate the pressure drop across the shell-tube heat exchanger (versus modeling hundreds of small pipes)

Problem Set-up:

- The entire CW assembly was modeled, from the lead-in duct to the discharge diffuser.
- Based on the earlier study on straight pipes, a length of 250 m was selected for the 4 m lead-in duct (this length can possibly be shortened in the future if more sophisticated ways of initializing the run are found).
- A "porous domain" model was chosen to simulate the pressure drop across the heat exchanger. This is a built-in feature of CFX, where the solver will simulate an area partially blocked by flow without the user actually having to model and mesh the blockage structure (i.e., the hundreds or thousands of internal tubes). The user can select parameters such as the fraction of area available for flow and resistance to flow.
- Although there is a heat exchanger in the assembly, buoyancy and heat transfer effects were still excluded to simplify the model, based on the assumption that the temperature change is not significant enough to greatly affect the fluid properties (i.e., density).
- Two symmetry planes at X=0 and Y=0 were used to decrease the mesh size and run time.

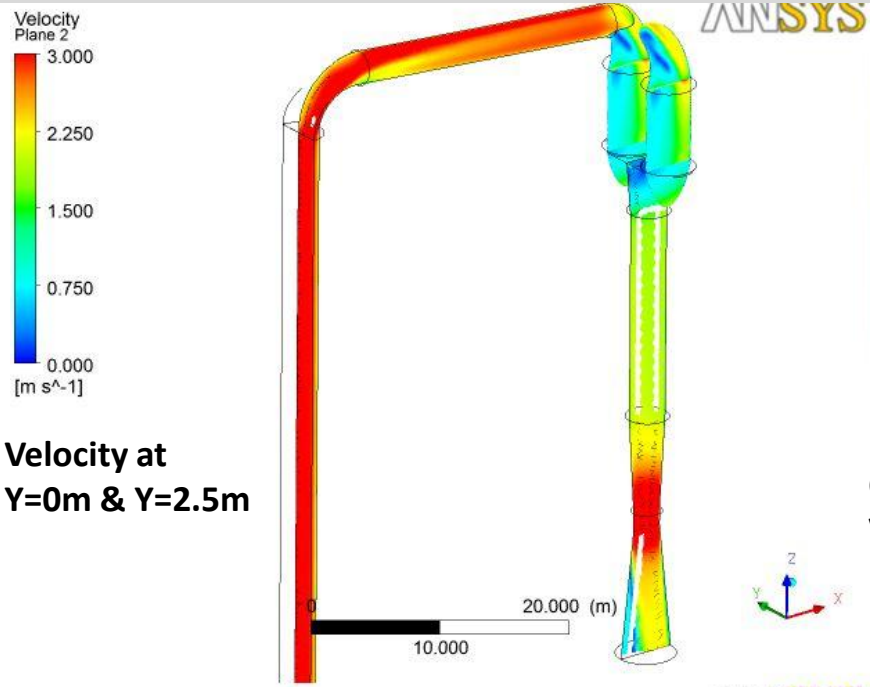
Mesh Size & Time Required:

- Number of nodes = 548,318
- Number of elements = 1,150,819
- Run time = 2 hours

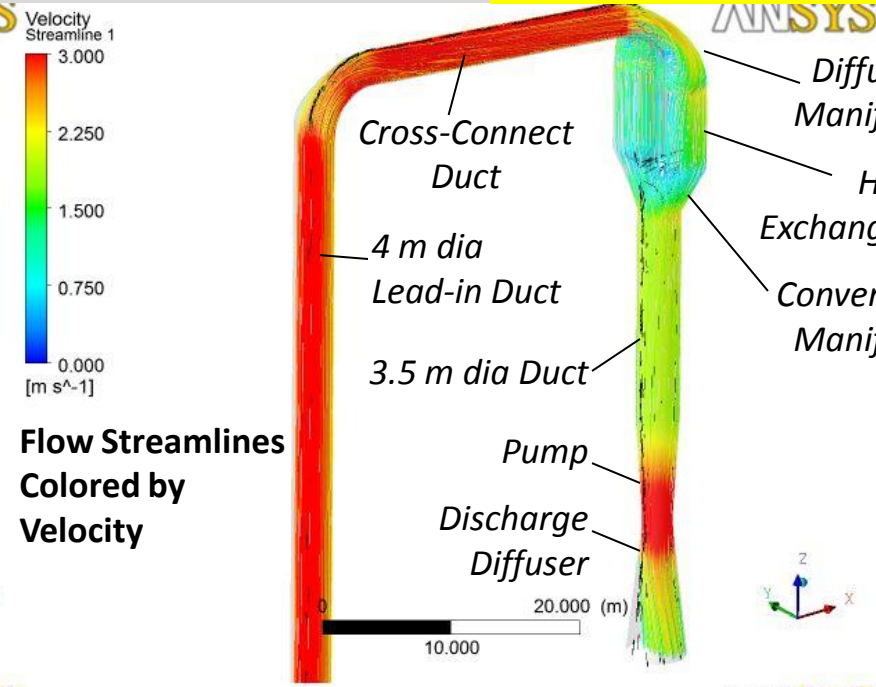
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Part 3 OTEC CW Assembly: Sample Results

PRELIMINARY RESULTS ONLY



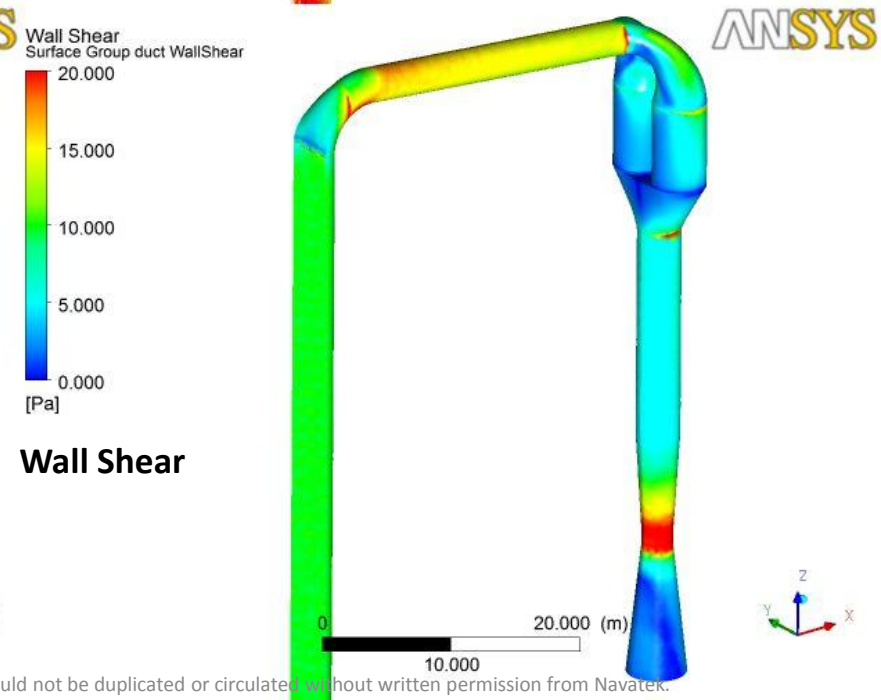
Velocity at Y=0m & Y=2.5m



Flow Streamlines Colored by Velocity



Velocity Cuts

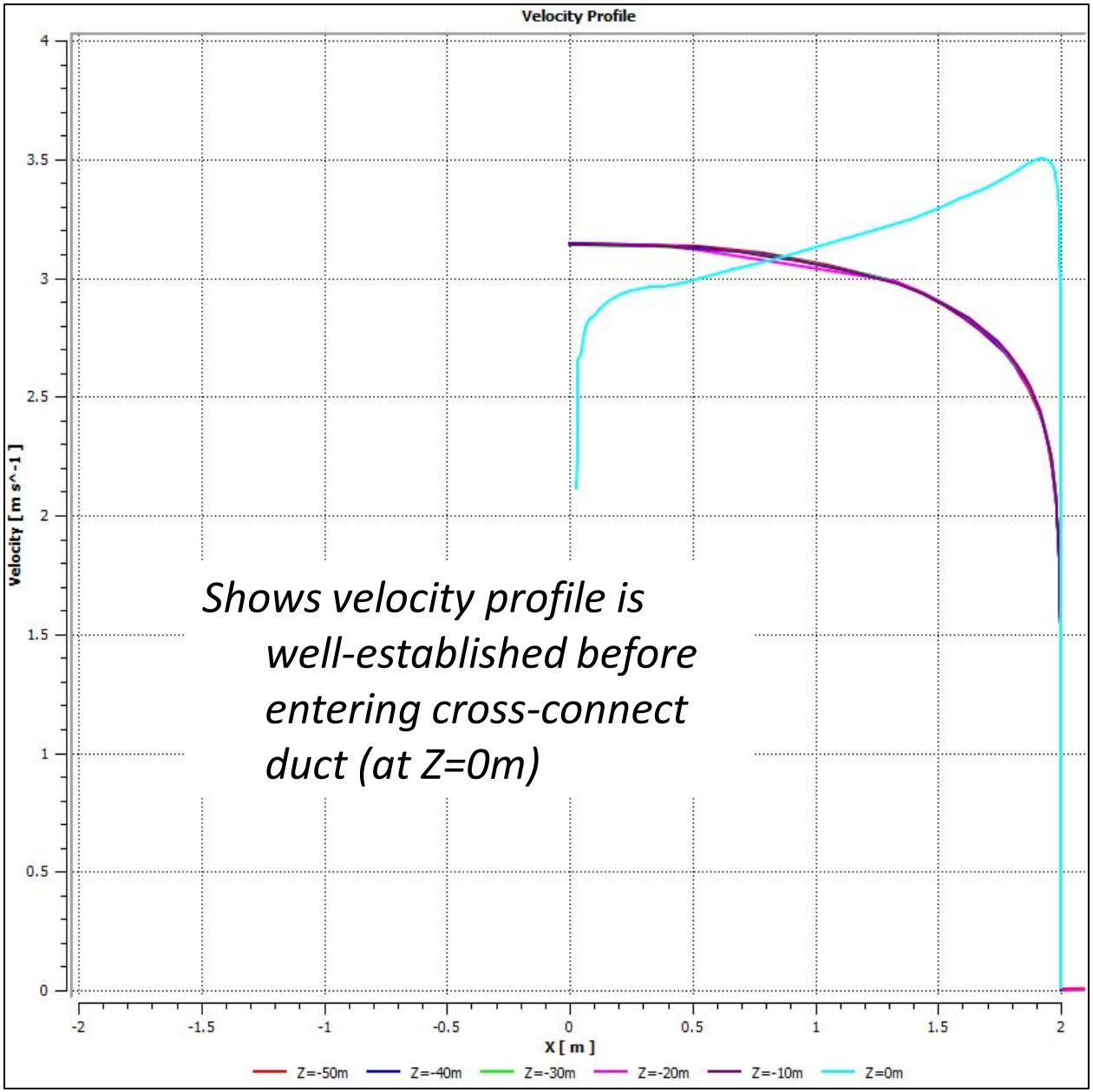


Wall Shear

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PRELIMINARY RESULTS ONLY

Velocity Profiles in last 50m of Lead-in Duct

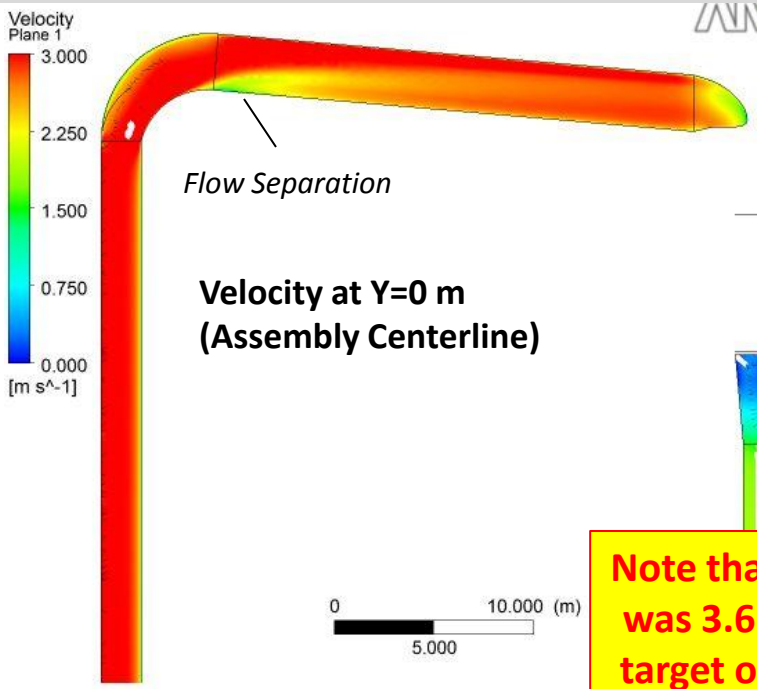


Shows velocity profile is well-established before entering cross-connect duct (at Z=0m)

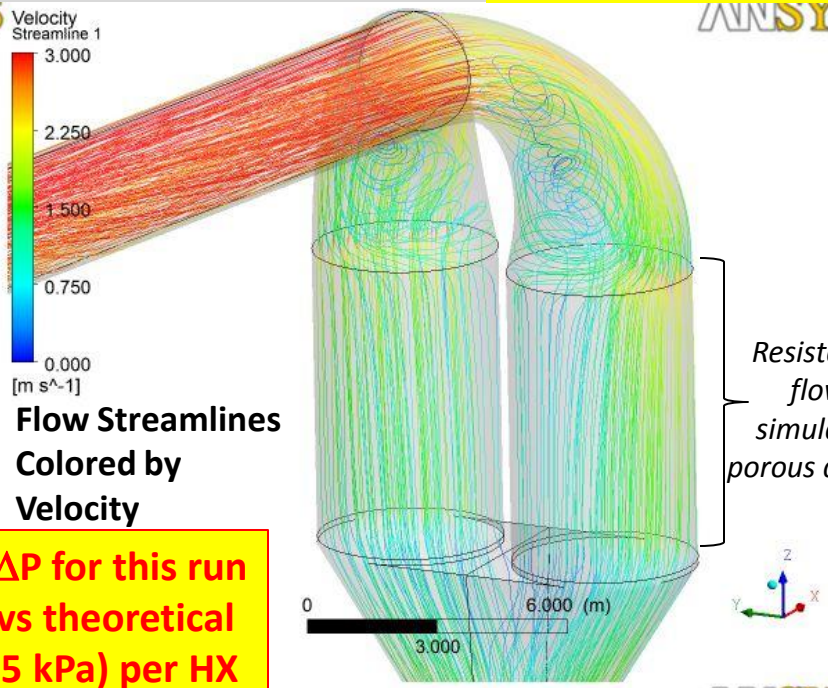
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Part 3 OTEC CW Assembly: Sample Results, Closer Look at HX

PRELIMINARY RESULTS ONLY

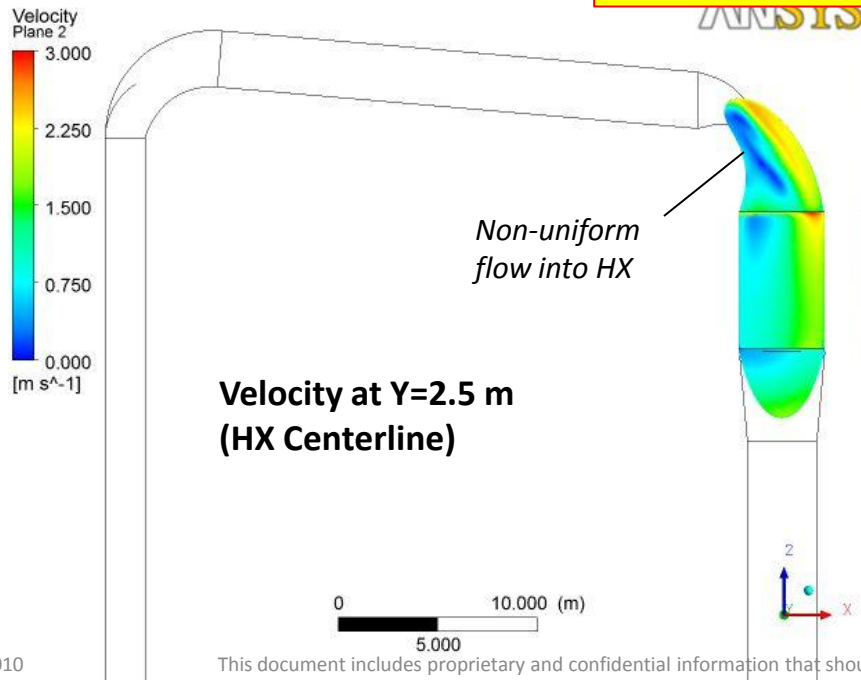


Velocity at Y=0 m (Assembly Centerline)

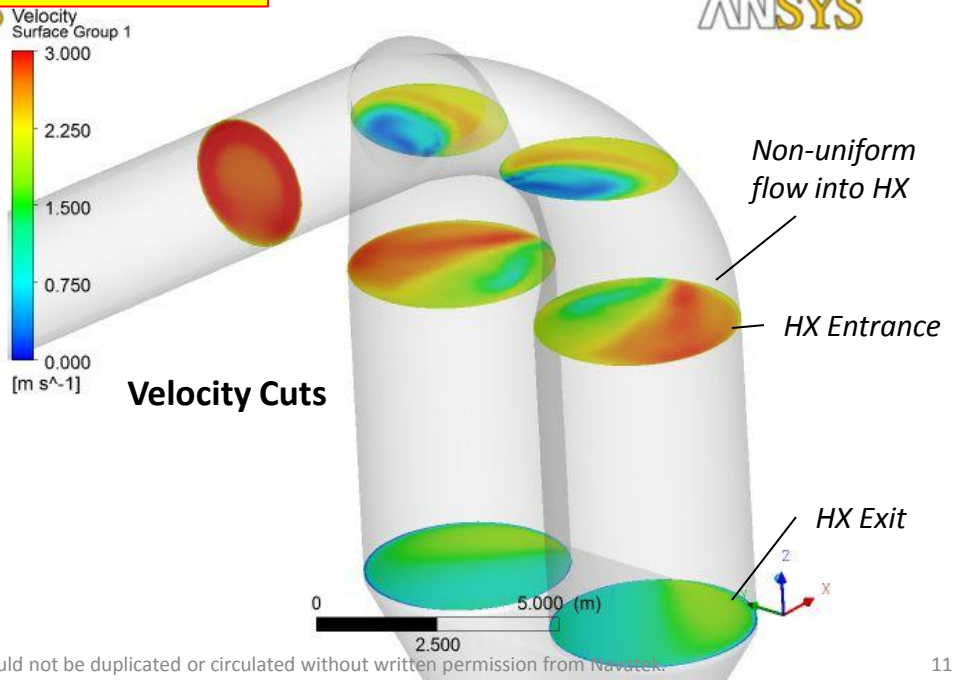


Flow Streamlines Colored by Velocity

Note that HX ΔP for this run was 3.6 kPa (vs theoretical target of 12.25 kPa) per HX



Velocity at Y=2.5 m (HX Centerline)



Velocity Cuts

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Summary

- Highlights:
  - A method to mesh and model the CW assembly was developed.
  - A means of simulating the pressure drop across the heat exchanger was found by using a "porous domain."
  - Flow details and head losses were visualized in the post-processor.
- Areas to Improve / Work on:
  - Tweak "porous domain" parameters to match estimated pressure drop across HX.
  - Incorporate geometry updates into the model.
  - Determine if refinement of mesh density in areas of interest is necessary (e.g., at top of CW assembly in the diffuser manifold).

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OTEC CW Assembly CFD: Status Update

Summary:

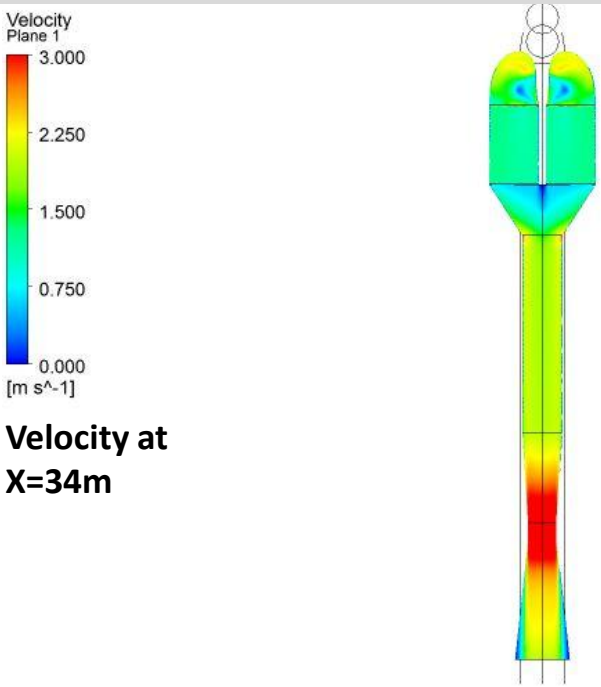
- The same mesh for the CW assembly as shown in the update last week (4/29/10) was used for this study .
- All parameters were kept the same as last week, except for the parameters of the porous domain. The porous domain parameters were varied to get the head loss across the heat exchanger (HX) closer to the theoretical prediction of **24.5 kPa**, and to bring the streamlines through the HX closer to vertical.
- For the results shown in the following slides, the CFX pressure drop predicted for the HX was **24.7 kPa**. The streamlines are now also vertical.
- Flow through the HX is not uniform across its cross-section due to the vorticity of the flow entering the HX .
- Next to do:
    - Incorporate geometry updates into the model (update cwtrunktop from v4 to v5).
    - Determine if refinement of mesh density in areas of interest is necessary (e.g., at the top of the CW assembly in the diffuser manifold).

OTEC CFX Settings		
Geometry	Type	CW Assembly (cwtrunktop v4)
	Diameter	Varies
	Lead-in Duct Length	250.00 m
Flow Properties	Fluid temperature	40 degF
	Fluid density	1027.742 kg/m^3
	Fluid kinematic viscosity	1.59e-6 m^2/s
	Volumetric flow rate	17.8 m^3/s
	Mass flow rate	18,294 kg/s
	Average velocity	Varies
	Reynolds number	Varies (>1e+6)
	Surface roughness FRP pipe	351e-6 m
	Surface roughness steel	60e-6 m
	Friction factor	0.01
CFD Solver	Software	ANSYS CFX v12
	Steady or unsteady	Steady
	Homogeneity	Homogeneous
	Turbulence model	SST, fully turbulent
	Buoyancy	None
	Heat transfer	None

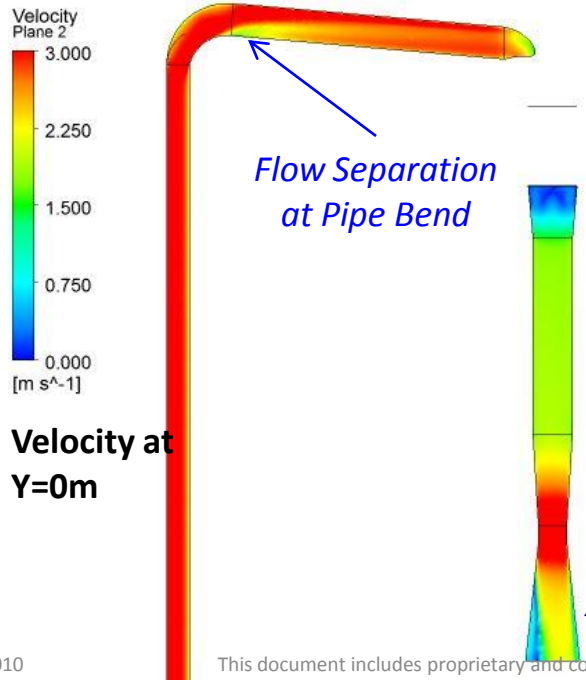
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OTEC CW Assembly CFD: Sample Results

PRELIMINARY RESULTS ONLY

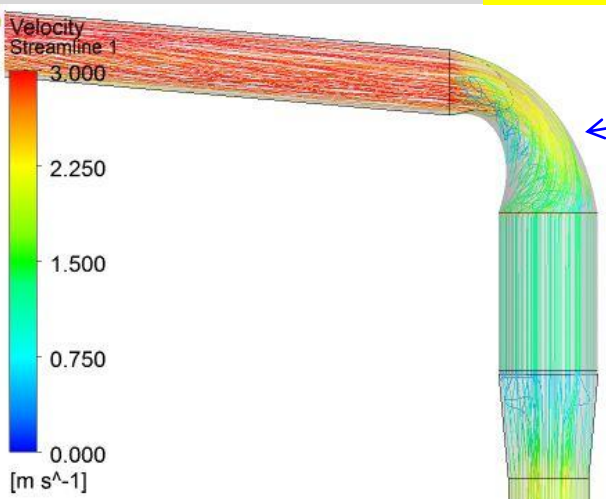


Velocity at X=34m



Velocity at Y=0m

Flow Separation at Pipe Bend



Flow Streamlines Colored by Velocity

Vorticity and non-uniform flow into HX

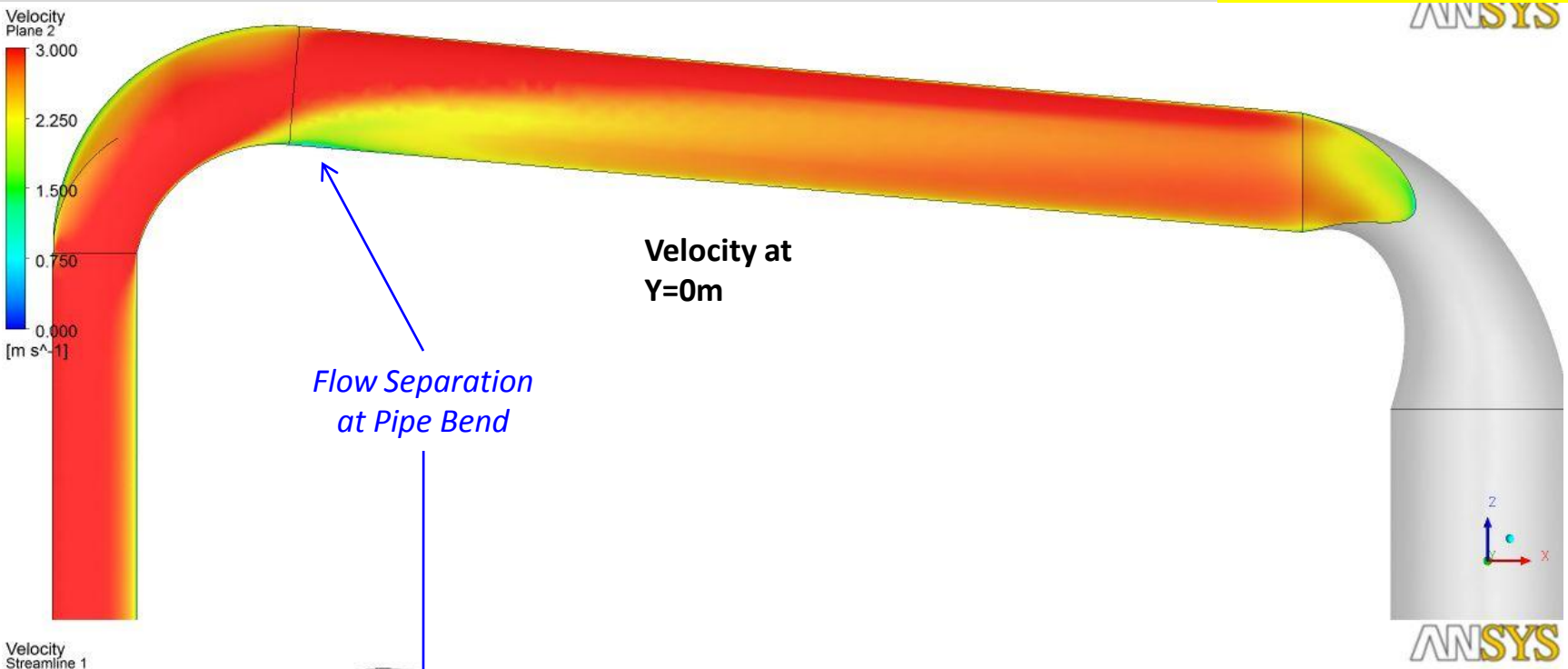
Streamlines closer to vertical

Non-uniform flow at discharge

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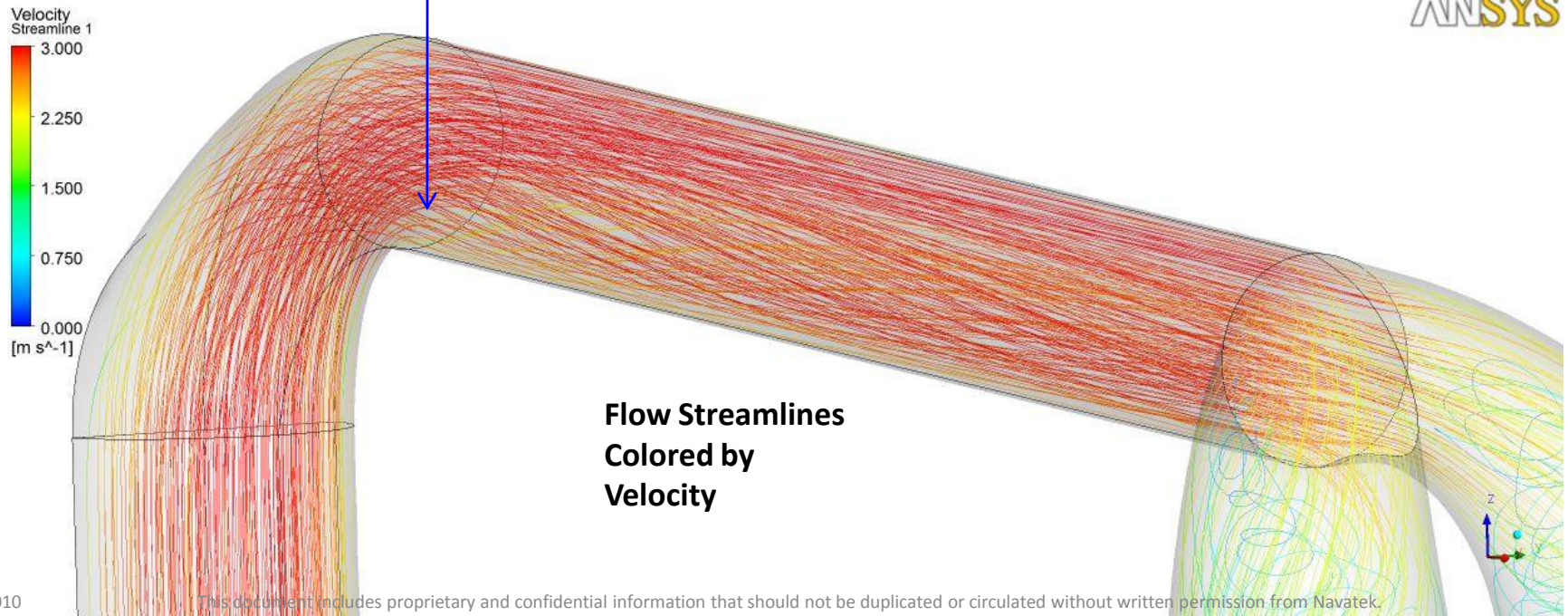
OTEC CW Assembly CFD: Sample Results

PRELIMINARY RESULTS ONLY



Velocity at Y=0m

Flow Separation at Pipe Bend

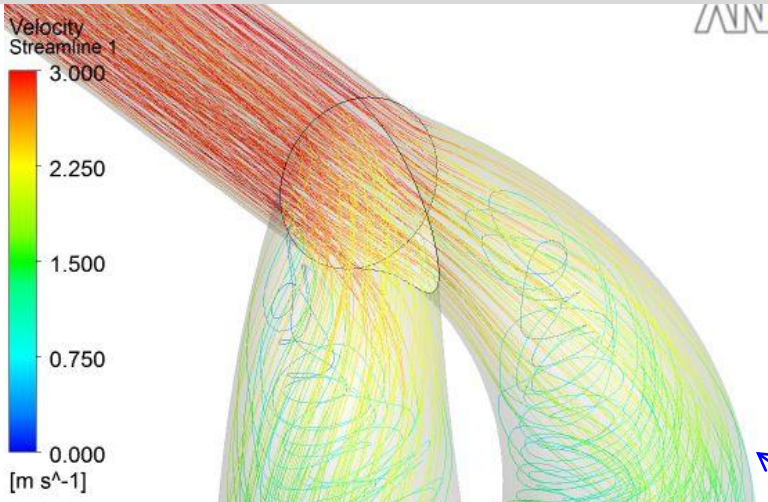


Flow Streamlines Colored by Velocity

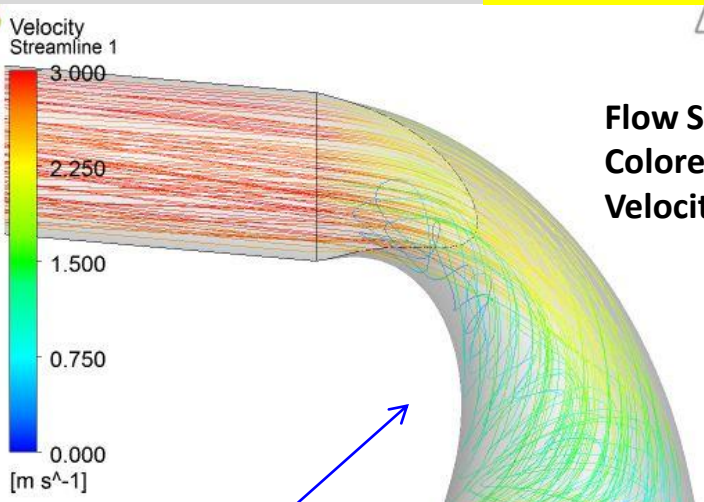
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OTEC CW Assembly CFD: Sample Results

PRELIMINARY RESULTS ONLY



Flow Streamlines Colored by Velocity



Flow Streamlines Colored by Velocity

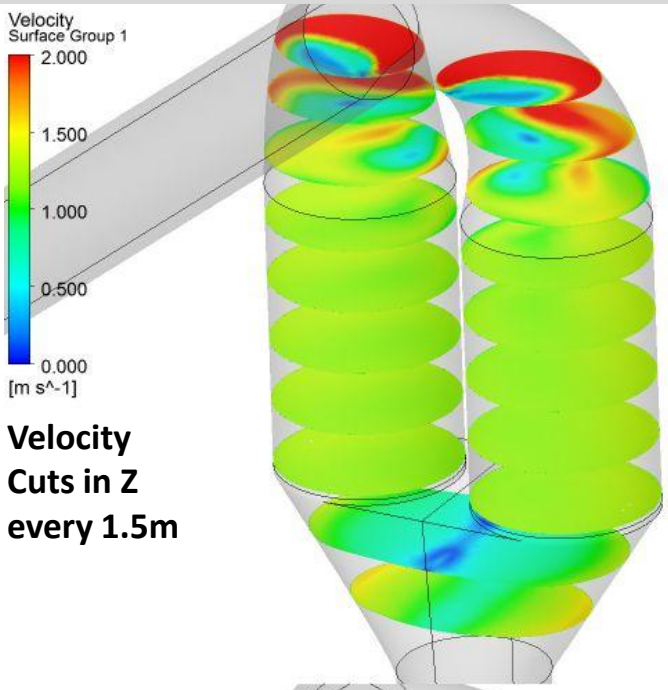
Vorticity in flow entering HX

Streamlines closer to vertical

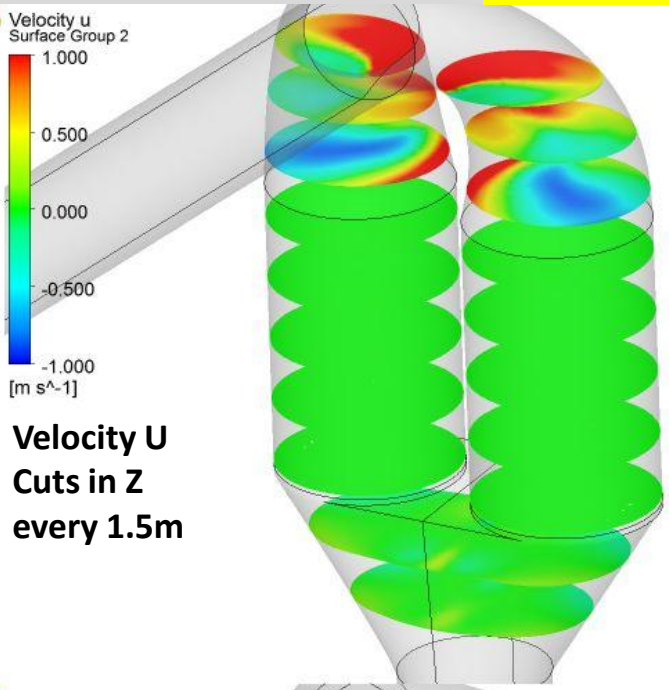
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OTEC CW Assembly CFD: Sample Results

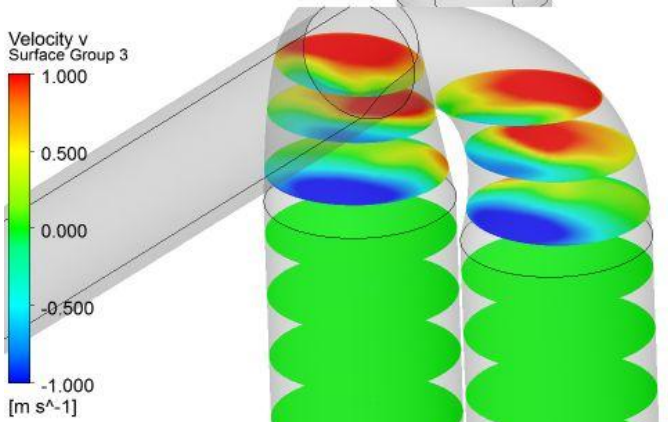
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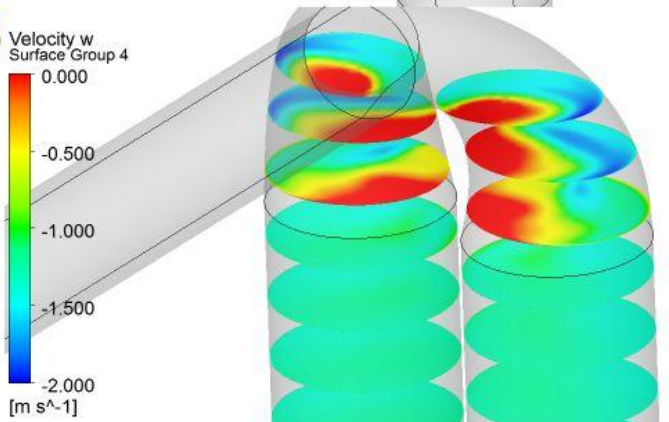
Velocity
Cuts in Z
every 1.5m



Velocity U
Cuts in Z
every 1.5m



Velocity V
Cuts in Z
every 1.5m

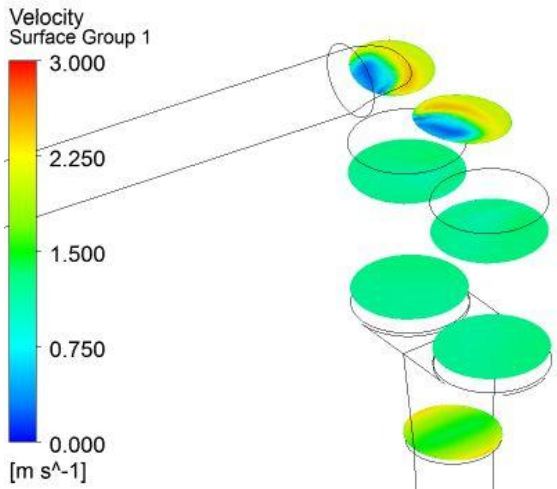


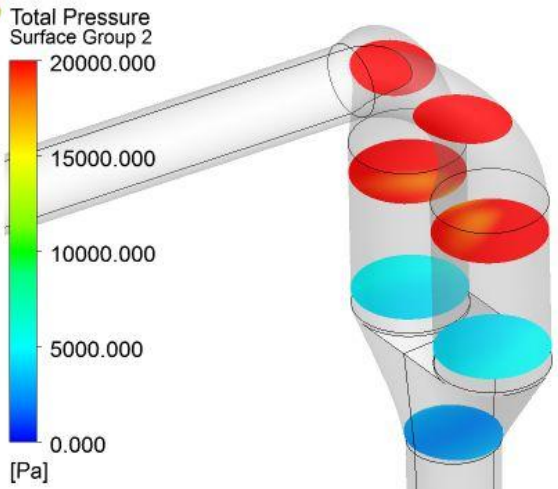
Velocity W
Cuts in Z
every 1.5m

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OTEC CW Assembly CFD: Sample Results

PRELIMINARY RESULTS ONLY





Non-uniform flow at discharge. Total Pressure is negative at outlet. Need to increase head available at inlet.

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OTEC CW Assembly CFD: Status Update

NAVATEK

Summary:

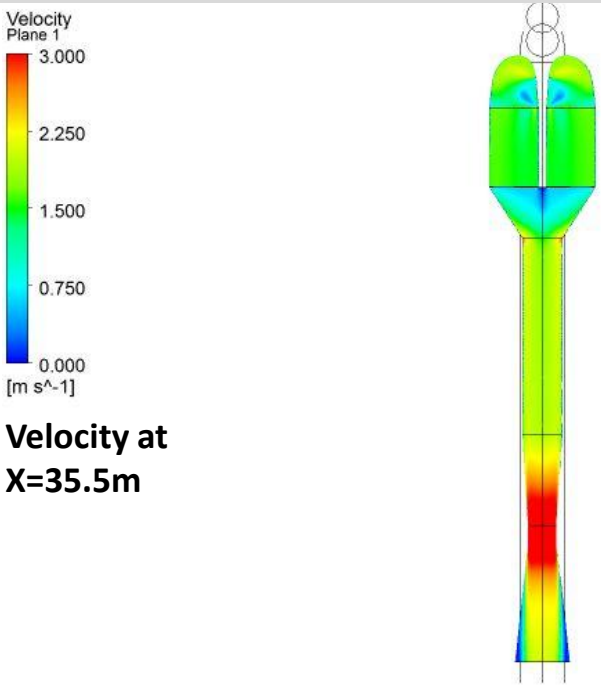
- A new mesh was created to incorporate the latest CW Diffuser Manifold (CW trunk top v5).
- The heat exchanger (HX) was modeled as a porous domain.
  - The porosity was set to the design value of 40%.
  - The resistance parallel to the flow direction was varied to get the pressure drop close to the theoretical prediction of 24.5 kPa.
  - The resistance perpendicular to the flow direction was increased to bring the streamlines through the HX closer to vertical.
- The surface roughness for the lead-in duct was set to the OTEC FRP surface roughness of 351 μm. The remainder of the assembly was left at a surface roughness for steel at 60 μm.
- Buoyancy (and gravity) were included in the model.
  - The waterline was set to 18.25 m above the entrance to the cross-connect duct (based on the ducting drawing provided by Makai).
  - No significant changes to the results were noted with the addition of buoyancy to the model.
- The mesh density at the two bends was increased 2x to confirm mesh convergence. Differences in losses predicted were < 1% between the finer mesh compared to the original mesh.
- Flow through the HX is not uniform across its cross-section due to the vorticity of the flow entering the HX .
- Next to do:
  - Incorporate any future design changes to improve the uniformity of flow into the heat exchangers.

OTEC CFX Settings		
Geometry	Type	CW Assembly (cwtrunktop v5)
	Diameter	Varies
	Lead-in Duct Length	250.00 m
Flow Properties	Fluid temperature	40 degF
	Fluid density	1027.742 kg/m^3
	Fluid kinematic viscosity	1.59e-6 m^2/s
	Volumetric flow rate	17.8 m^3/s
	Mass flow rate	18,294 kg/s
	Average velocity	Varies
	Reynolds number	Varies (>1e+6)
	Surface roughness FRP pipe	351e-6 m
	Surface roughness steel	60e-6 m
	Friction factor	0.01
CFD Solver	Software	ANSYS CFX v12
	Steady or unsteady	Steady
	Homogeneity	Homogeneous
	Turbulence model	SST, fully turbulent
	Buoyancy	Included
	Heat transfer	None

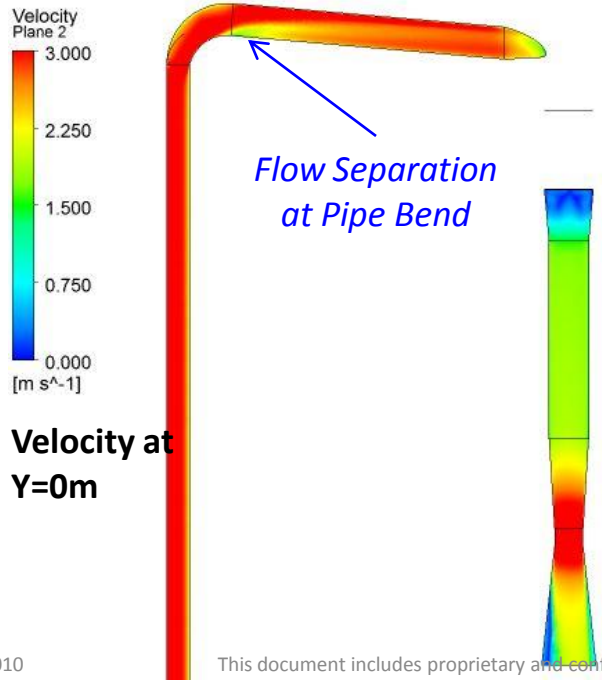
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OTEC CW Assembly CFD: Status Update

PRELIMINARY RESULTS ONLY

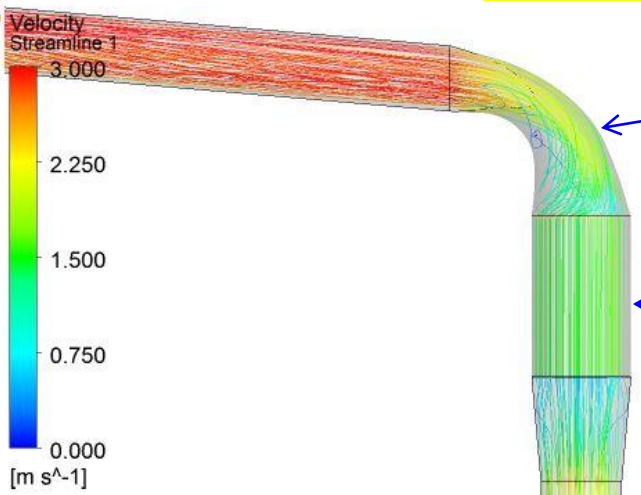


Velocity at X=35.5m



Velocity at Y=0m

Flow Separation at Pipe Bend



Flow Streamlines Colored by Velocity

Vorticity and non-uniform flow into HX

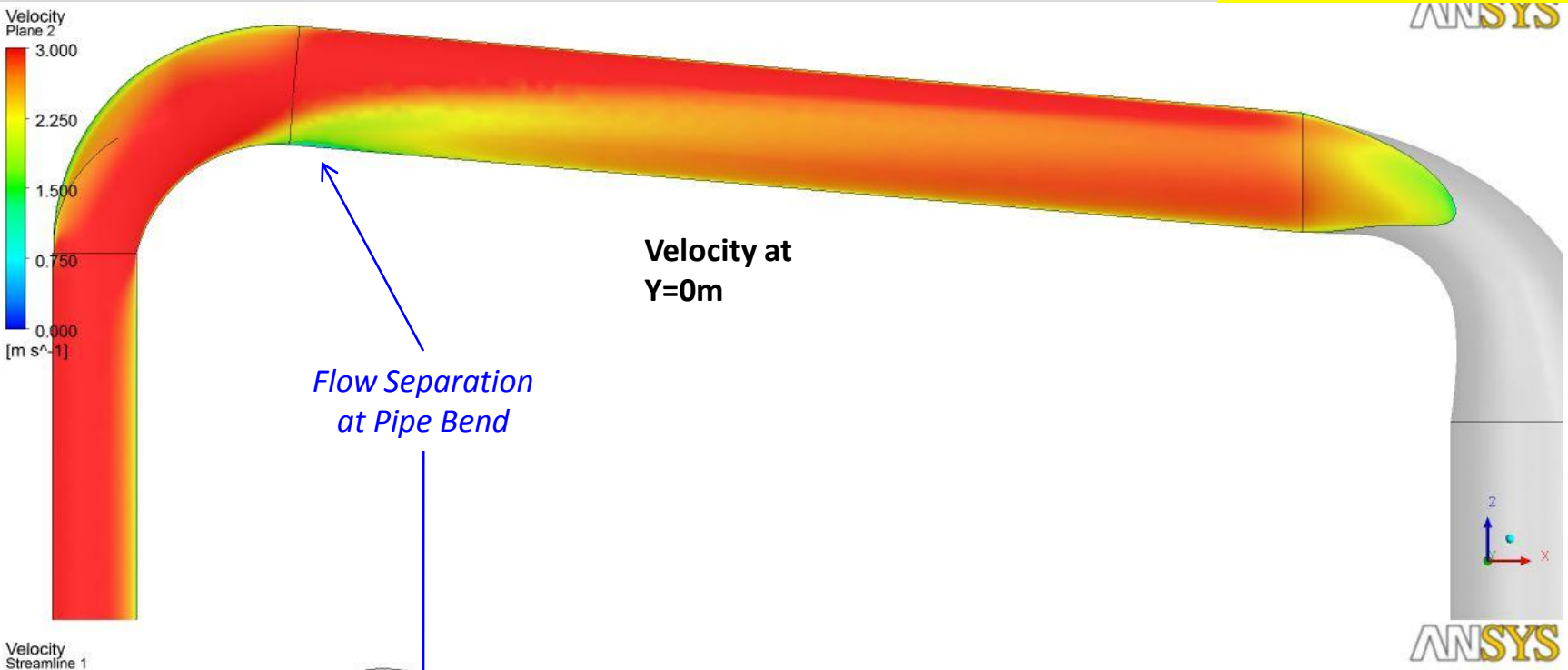
Streamlines closer to vertical

Non-uniform flow at discharge

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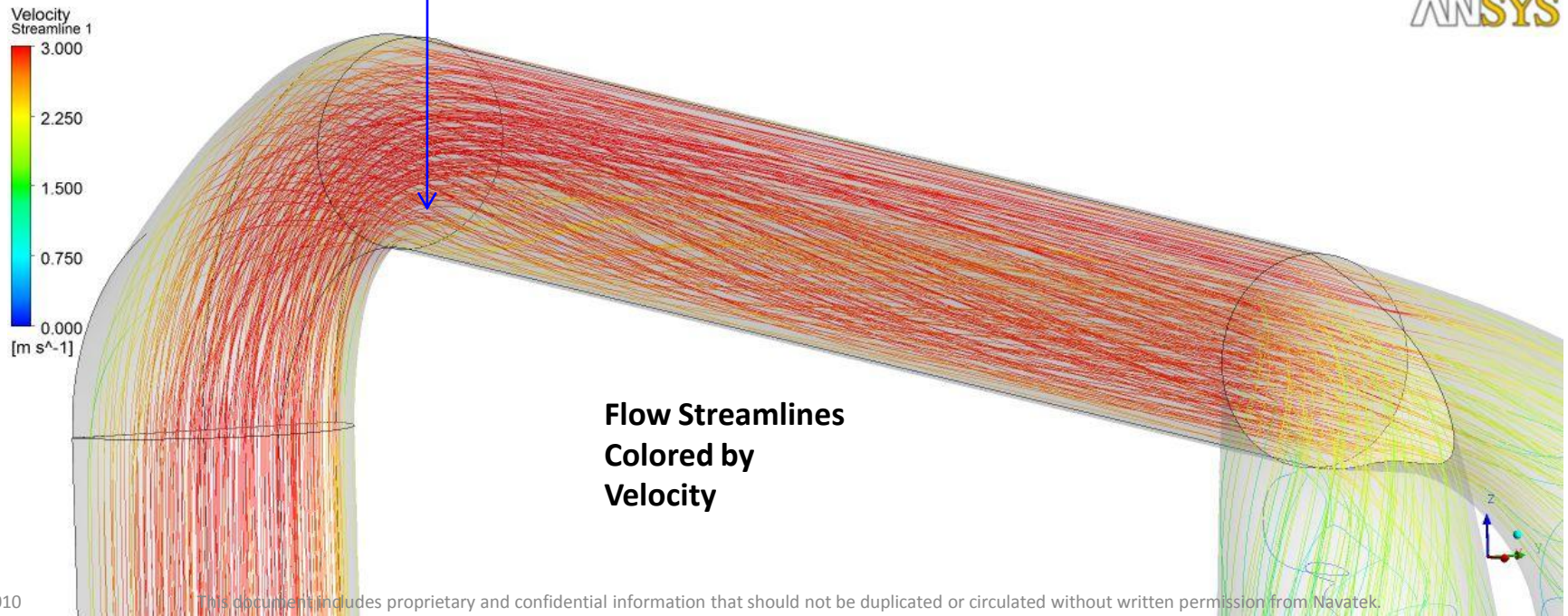
OTEC CW Assembly CFD: Status Update

PRELIMINARY RESULTS ONLY



Velocity at Y=0m

Flow Separation at Pipe Bend

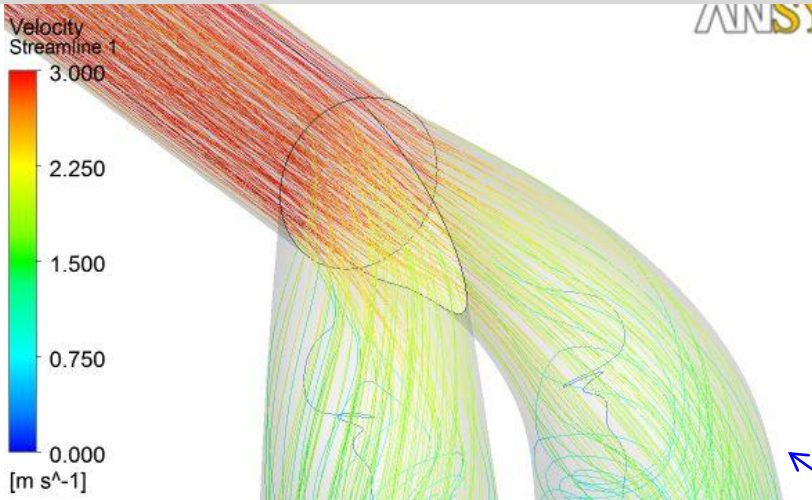


Flow Streamlines Colored by Velocity

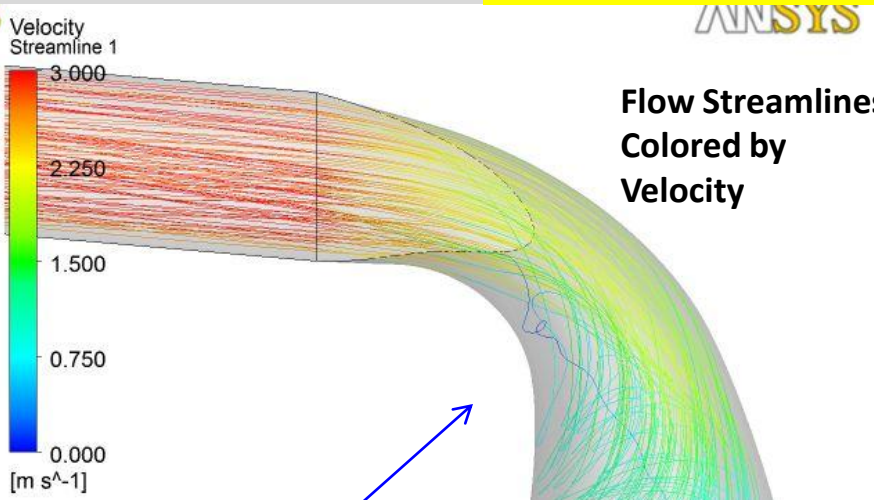
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OTEC CW Assembly CFD: Status Update

PRELIMINARY RESULTS ONLY



Flow Streamlines Colored by Velocity



Flow Streamlines Colored by Velocity

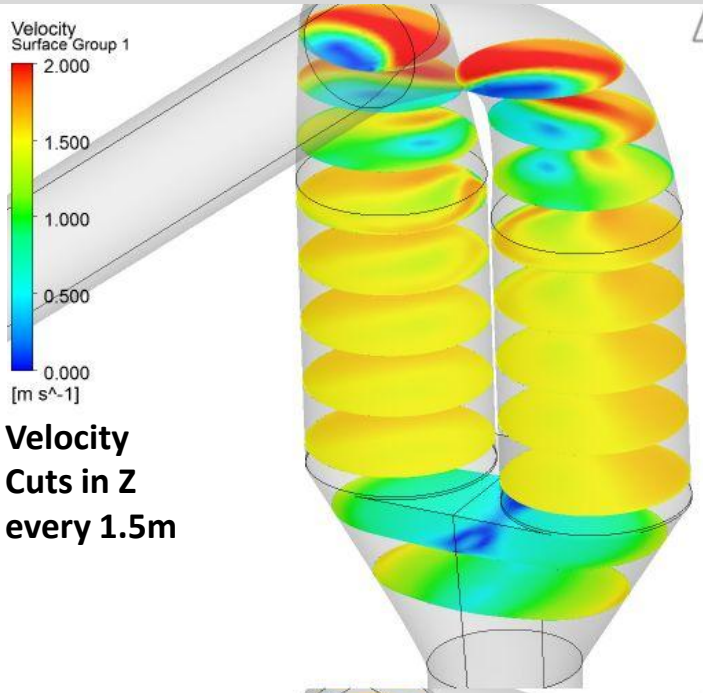
Vorticity in flow entering HX

Streamlines closer to vertical

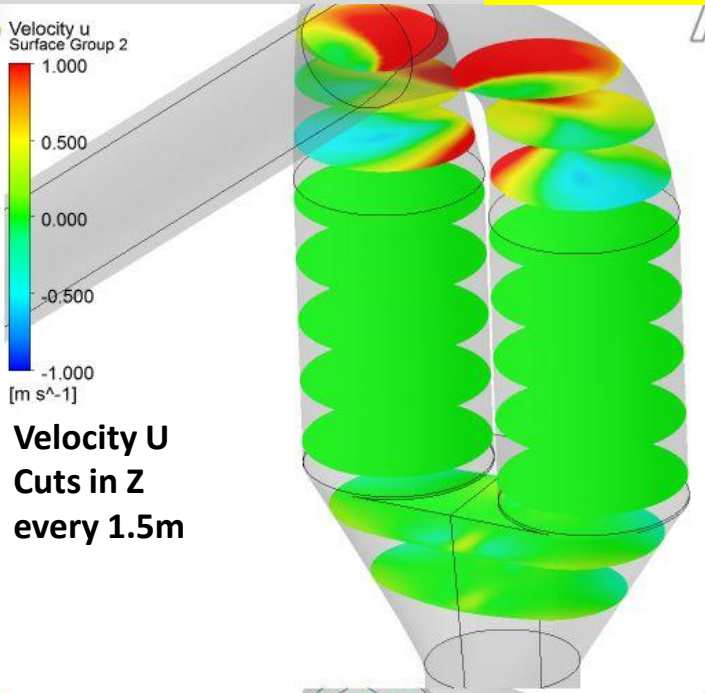
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OTEC CW Assembly CFD: Status Update

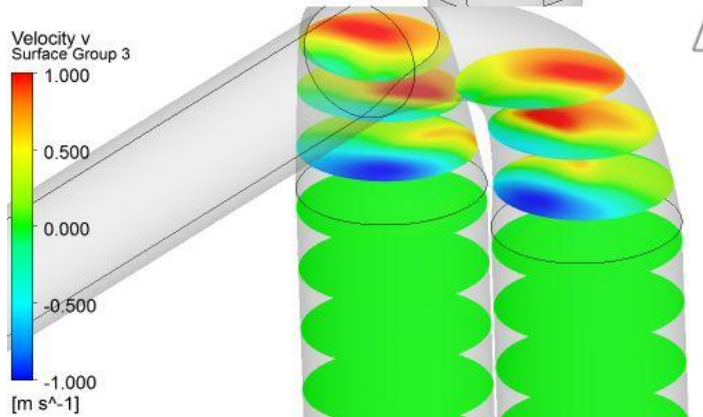
PRELIMINARY RESULTS ONLY



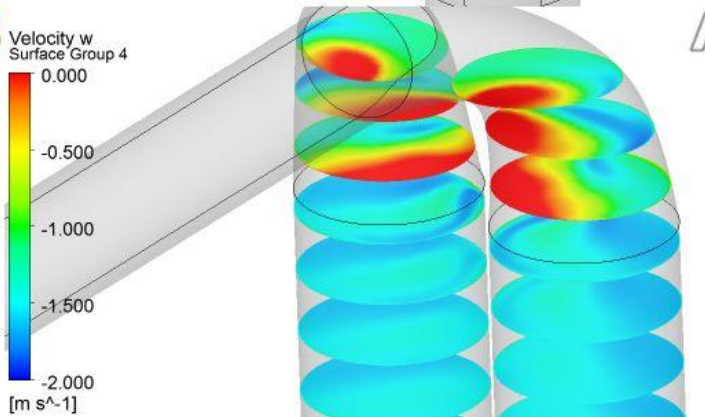
Velocity
Cuts in Z
every 1.5m



Velocity U
Cuts in Z
every 1.5m



Velocity V
Cuts in Z
every 1.5m

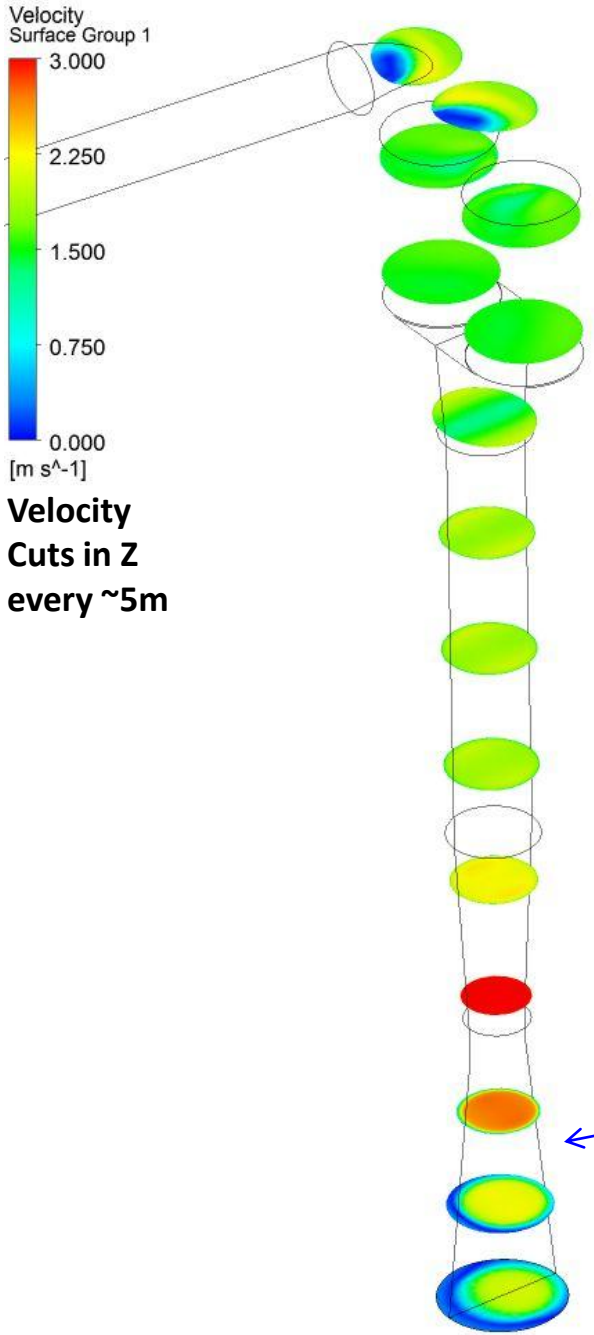


Velocity W
Cuts in Z
every 1.5m

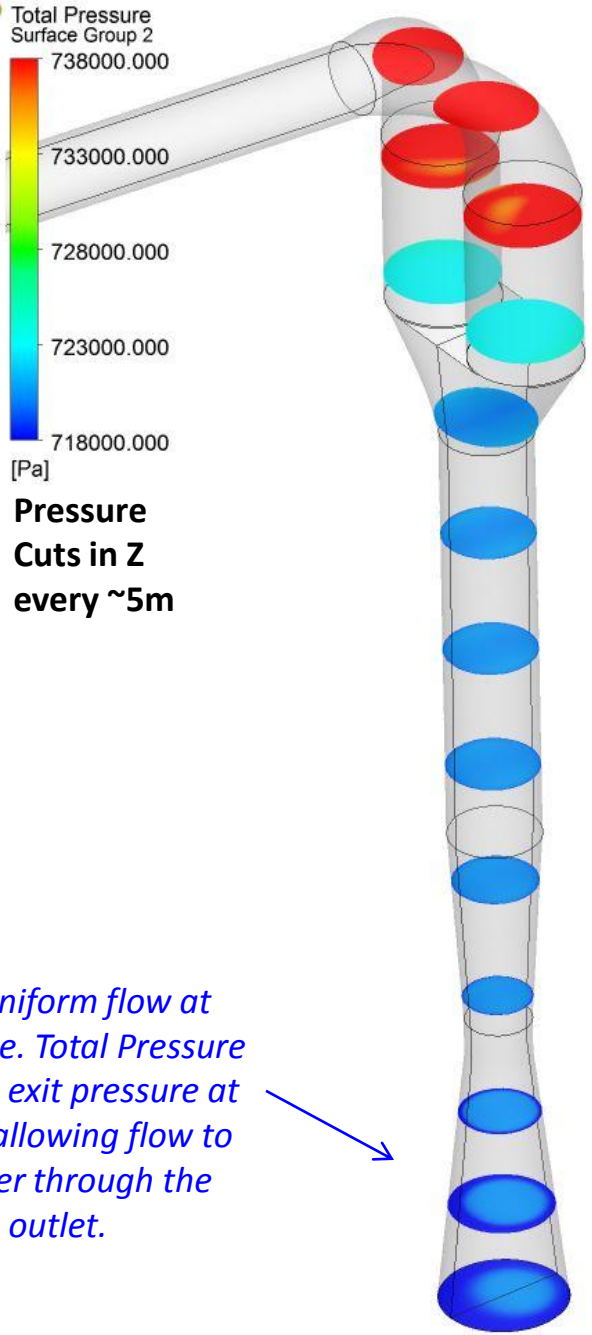
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OTEC CW Assembly CFD: Status Update

PRELIMINARY RESULTS ONLY



Velocity
Cuts in Z
every ~5m



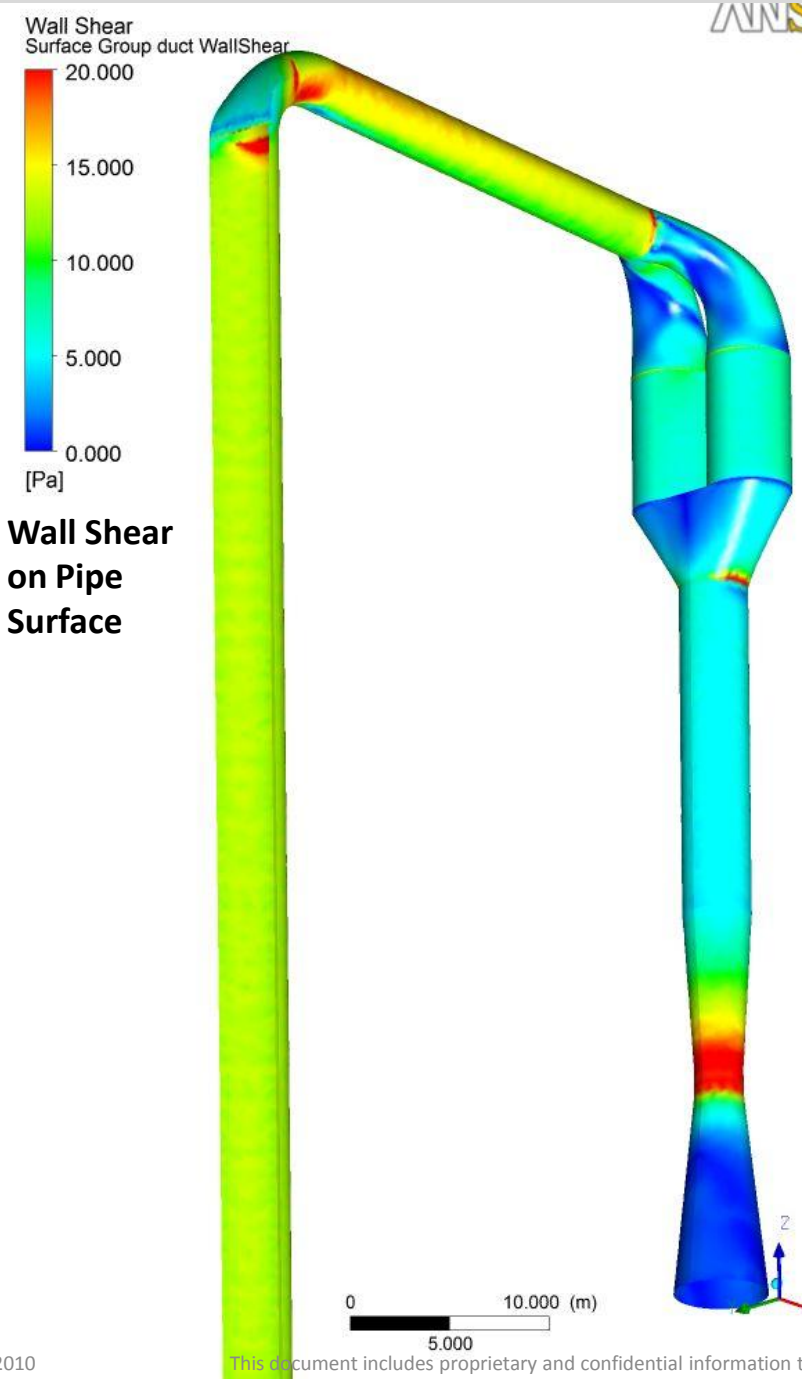
Pressure
Cuts in Z
every ~5m

Non-uniform flow at discharge. Total Pressure is below exit pressure at outlet, allowing flow to re-enter through the outlet.

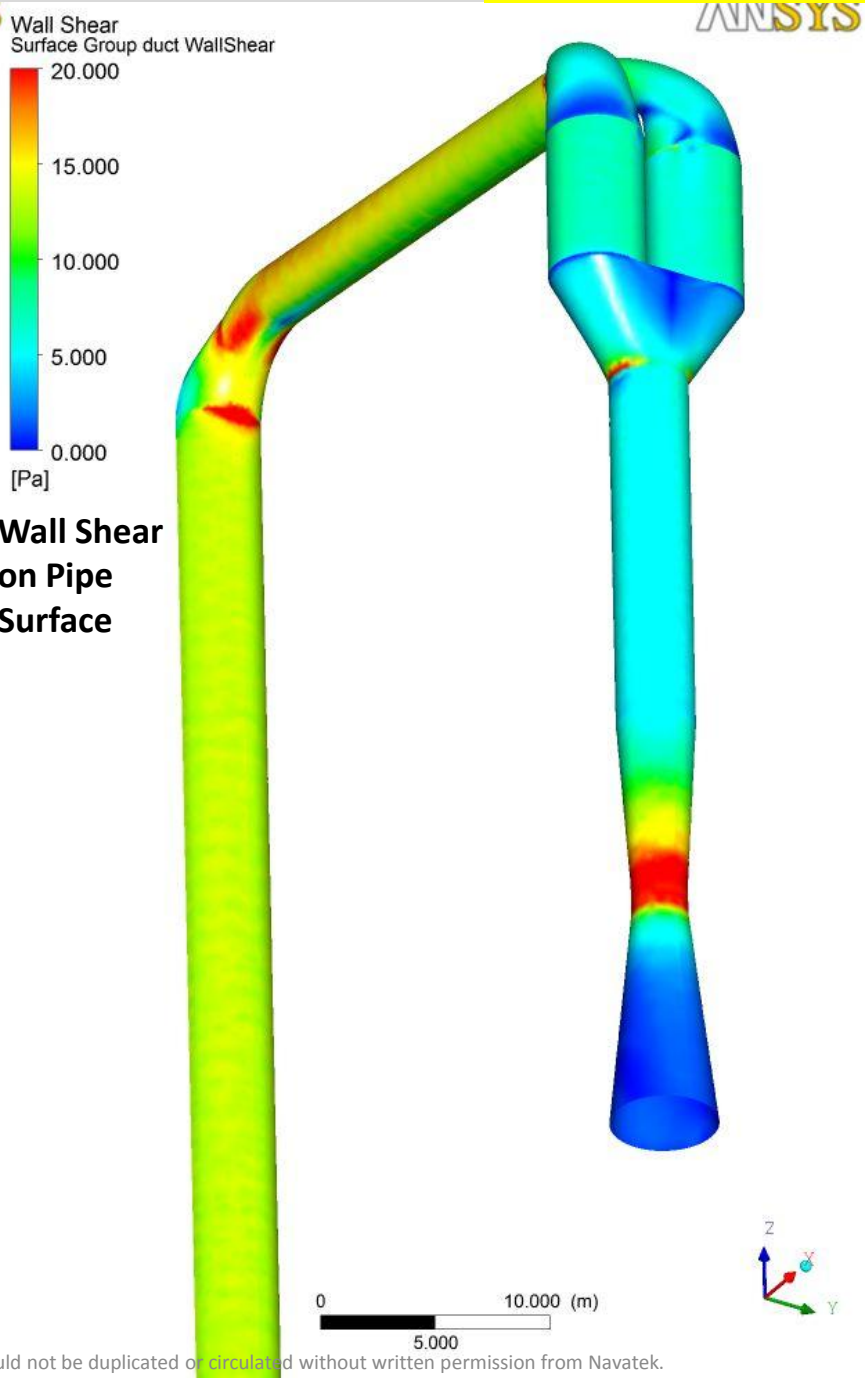
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OTEC CW Assembly CFD: Status Update

PRELIMINARY RESULTS ONLY



Wall Shear on Pipe Surface



Wall Shear on Pipe Surface

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OTEC Cold Water Assembly CFD: Status Update

10 June 2010

Prepared by:
M. Parish
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(808) 531-7001 x31

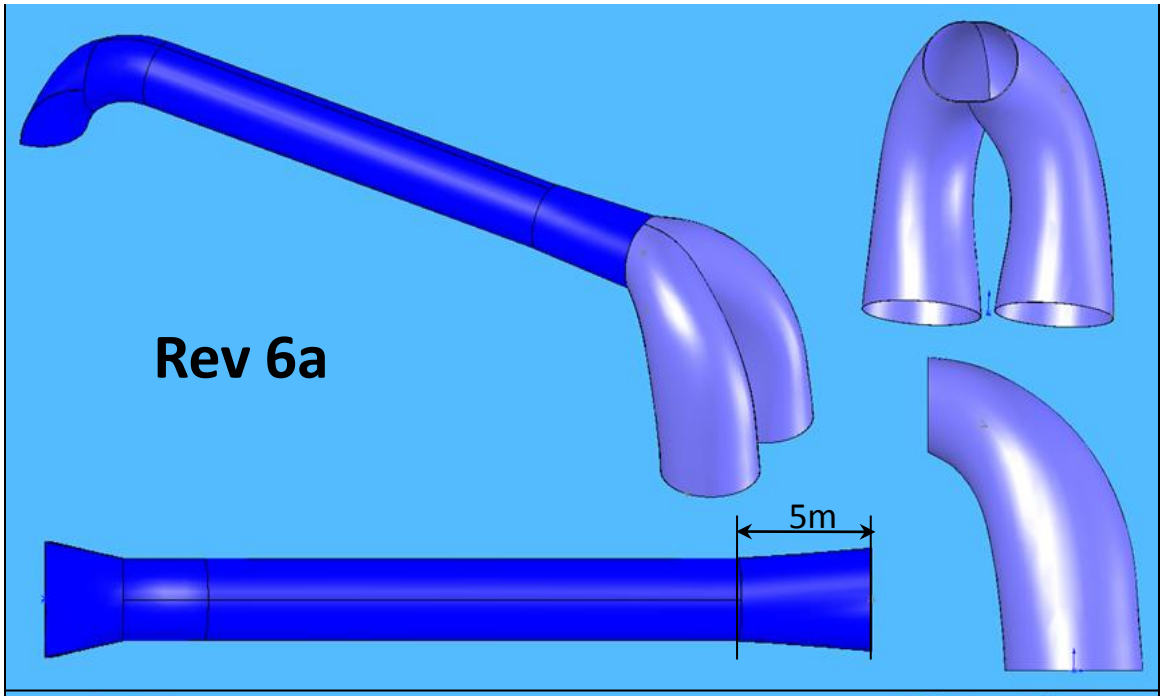
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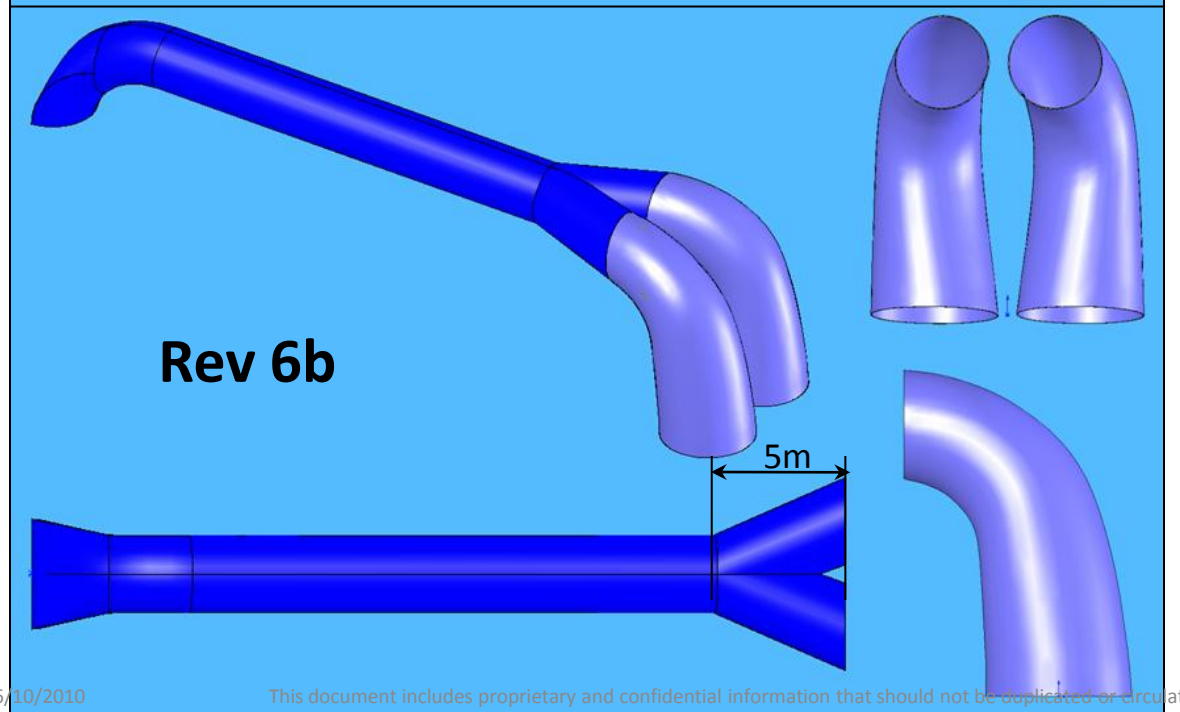
Problem Set-up

- A CFD analysis was performed on two new geometries for the OTEC Cold Water (CW) Assembly.
- The results from a total of three geometries were compared: CW assembly v2, v3, and v4.
  - CW Assembly v3 and v4 contain the latest version of the discharge diffuser (v2).
  - CW assembly v2 contains v5 of the top piece (CW diffuser manifold, top split and bend). These results have been shared in a previous status update.
  - CW assembly v3 contains v6a of the top piece, with the cross-connect duct modified to fit the new top piece.
  - CW assembly v4 contains v6b of the top piece, with the cross-connect duct modified to fit the new top piece.
- Buoyancy (and gravity) were included in the model, and heat transfer was not included in the model.
  - The waterline was set to 18.25 m above the entrance to the cross-connect duct (based on the ducting drawing provided by Makai).
  - No significant changes to the results were noted with the addition of buoyancy to the model.

OTEC CFX Settings		
Geometry	CW assembly v2	Top piece (v5)
	CW assembly v3	Top piece (v6a) Discharge diffuser (v2)
	CW assembly v4	Top piece (v6b) Discharge diffuser (v2)
	Lead-in Duct Length	250.00 m
Flow Properties	Fluid temperature	40 degF
	Fluid density	1027.742 kg/m^3
	Fluid kinematic viscosity	1.59e-6 m^2/s
	Volumetric flow rate	17.8 m^3/s
	Mass flow rate	18,294 kg/s
	Average velocity	Varies
	Reynolds number	Varies (>1e+6)
	Surface roughness FRP pipe	351e-6 m
	Surface roughness steel	60e-6 m
	Friction factor	0.01
CFD Solver	Software	ANSYS CFX v12
	Steady or unsteady	Steady
	Homogeneity	Homogeneous
	Turbulence model	SST, fully turbulent
	Buoyancy	Included
	Heat transfer	None

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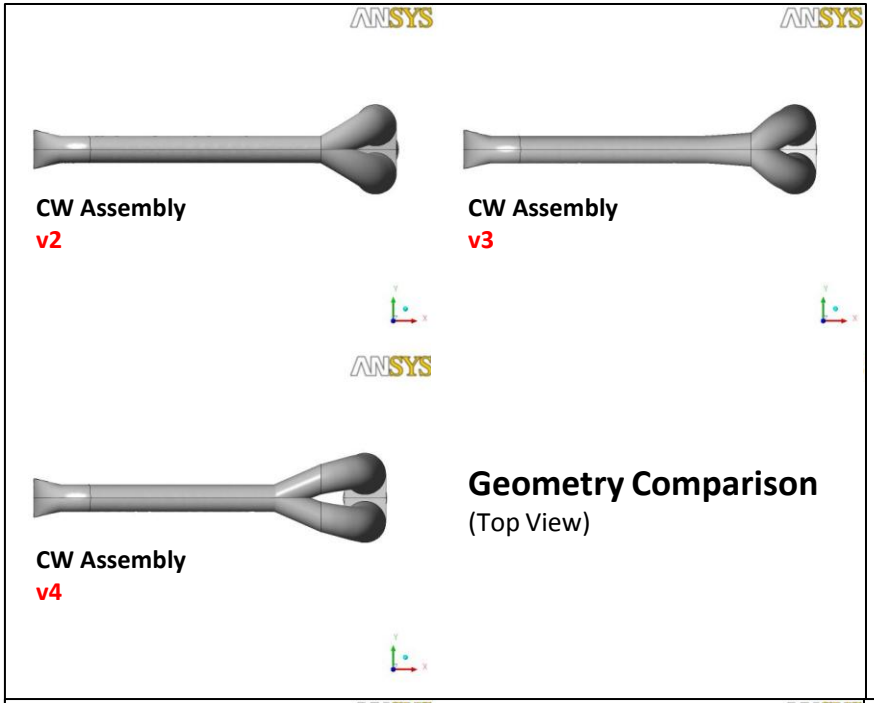




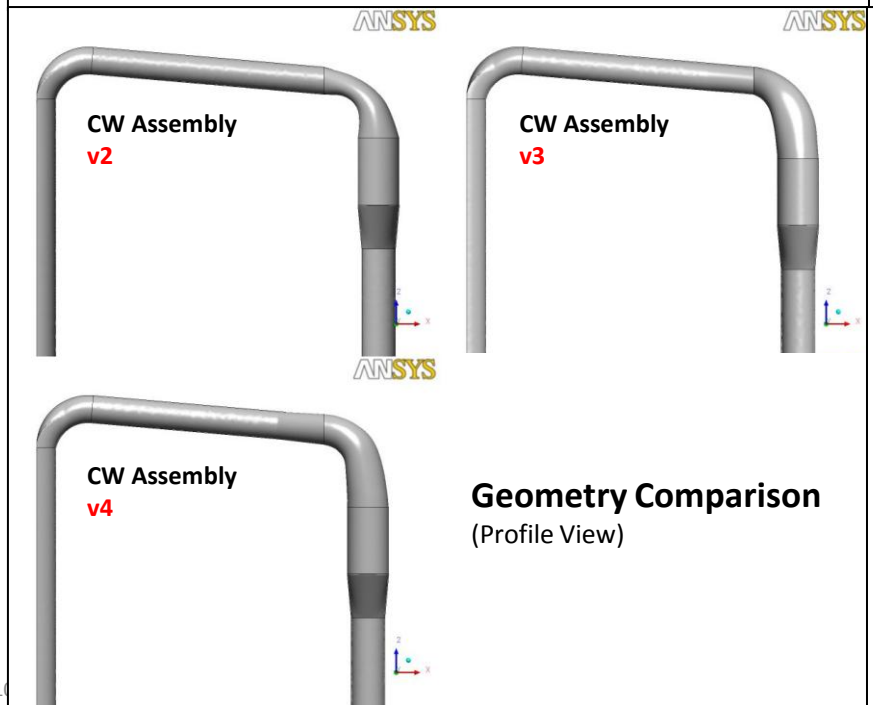
Changes to Cross-connect and Top Piece (CW Diffuser Manifold Split & Bend)

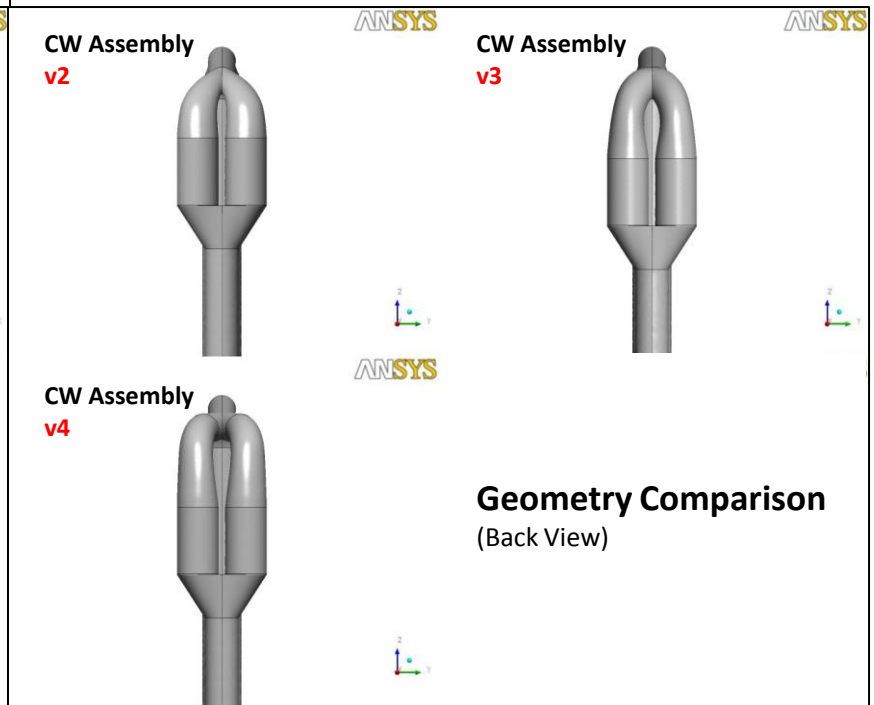
- Changes were made to the top piece (CW diffuser manifold containing split and bend) in order to reduce the vorticity of flow in this area and improve the uniformity of flow entering the heat exchanger.
- The diameter was increased to slow the flow down, and the shape modified to improve the flow.
- The cross-connect duct was modified as well to accommodate the changes in the top pieces.
- Cross-connect and top piece v6a (in CW assembly v3):
  - 11% increase in diameter
  - 25% increase in cross-sectional area
  - Attempt to reduce flow velocity from 2.5 m/s to 2.0 m/s
  - Quasi-elliptical cross-section
  - Improved transition from horizontal to vertical
- Cross-connect and top piece v6b (in CW assembly v4):
  - 11% increase in diameter
  - 25% increase in cross-sectional area
  - Attempt to reduce flow velocity from 2.5 m/s to 2.0 m/s
  - Split earlier in cross-over pipe
  - Circular cross-sections
  - Improved transition from horizontal to vertical

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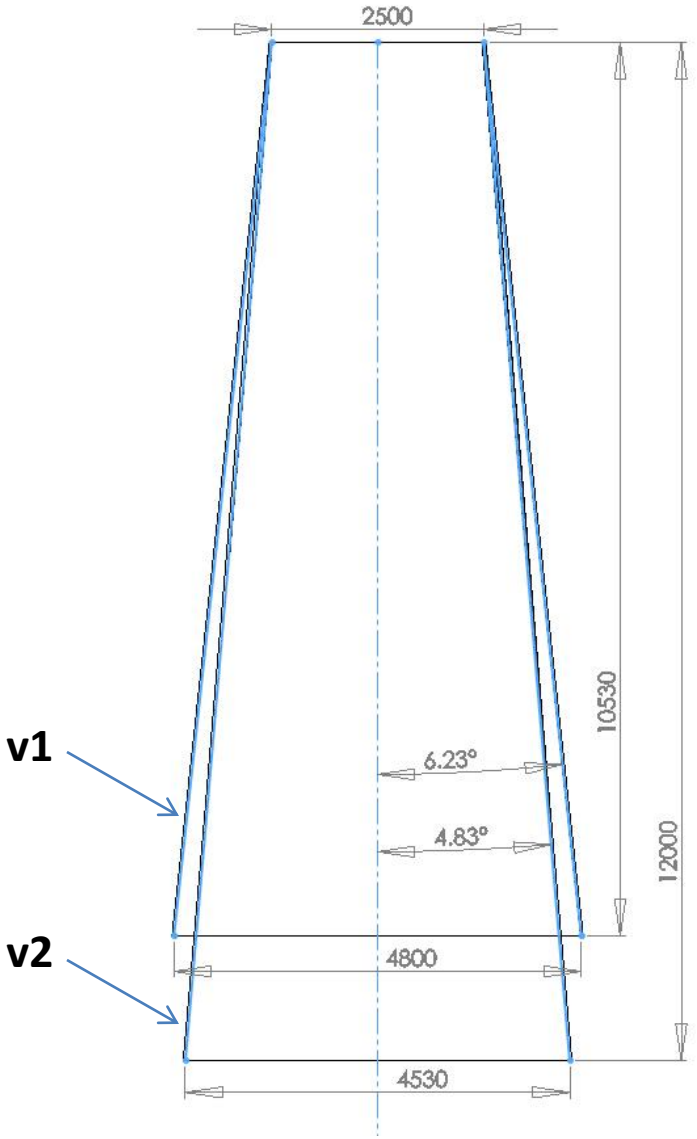
Geometry Comparison: Changes to Cross-connect and Top Piece (CW Diffuser Manifold Split & Bend)





Changes to Discharge Diffuser

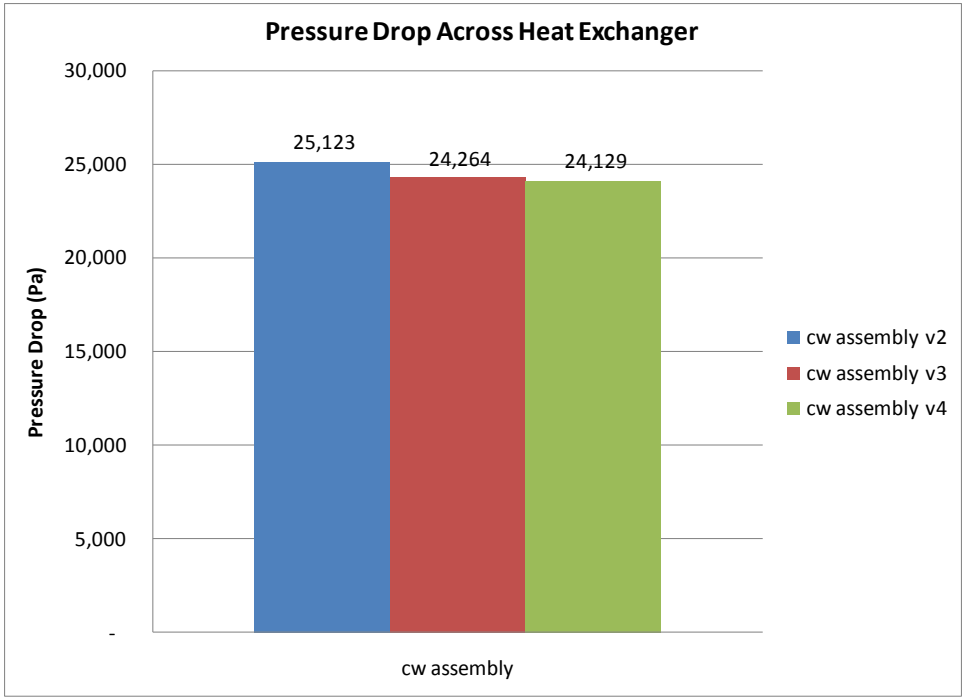
- The discharge diffuser at the bottom of the CW assembly was modified to reduce the recirculation of flow observed at the exit of the CW assembly.
- The diffuser angle was decreased, and the length increased from v1 to v2.



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Pressure Drop Across HX

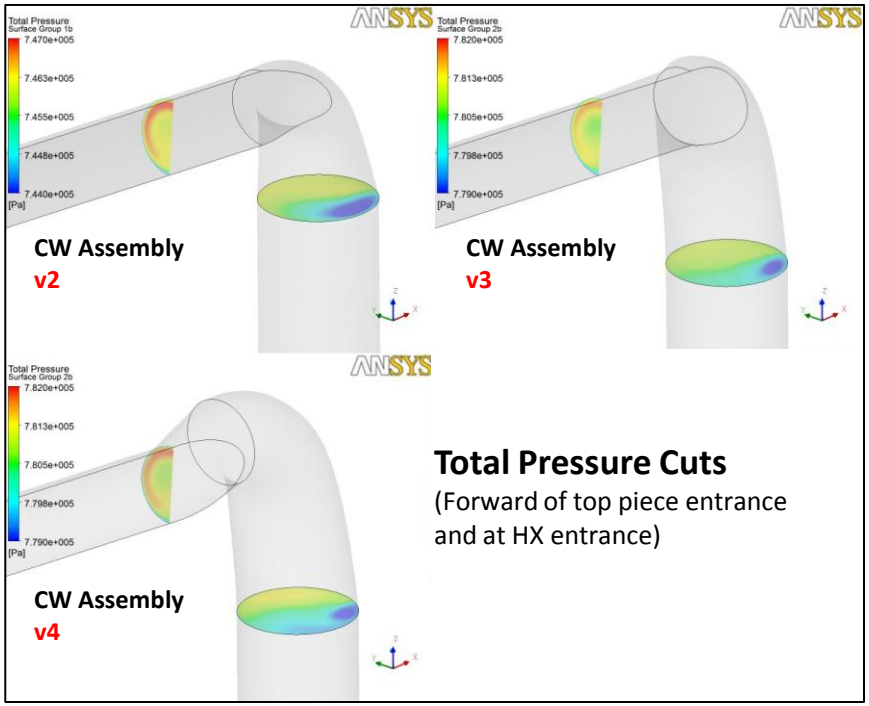
- The Cold Water (CW) Heat Exchanger (HX) was modeled as a porous domain.
  - The porosity was set to the design value of 40%.
  - The resistance parallel to the flow direction was set to 8500 kg/m^4, where the aim was to get the pressure drop across the HX close to the theoretical prediction of 24.5 kPa.
  - The resistance perpendicular to the flow direction was set to 100x the resistance parallel to the flow direction to bring the streamlines through the HX closer to vertical.
- The parameters for the porous domain were kept consistent across all models to be able to compare the different designs.
- A mass flow average was taken at the entrance and exit of the HX to calculate the pressure drop.
- Compared to the pressure drop across the HX for v1 of the CW assembly, the pressure drop was 3.4% lower for v2, and 4.0% lower for v3.
- (For further comparison and study, the parameters for the HX could also be varied so that the pressure drop was consistent for all three versions.)

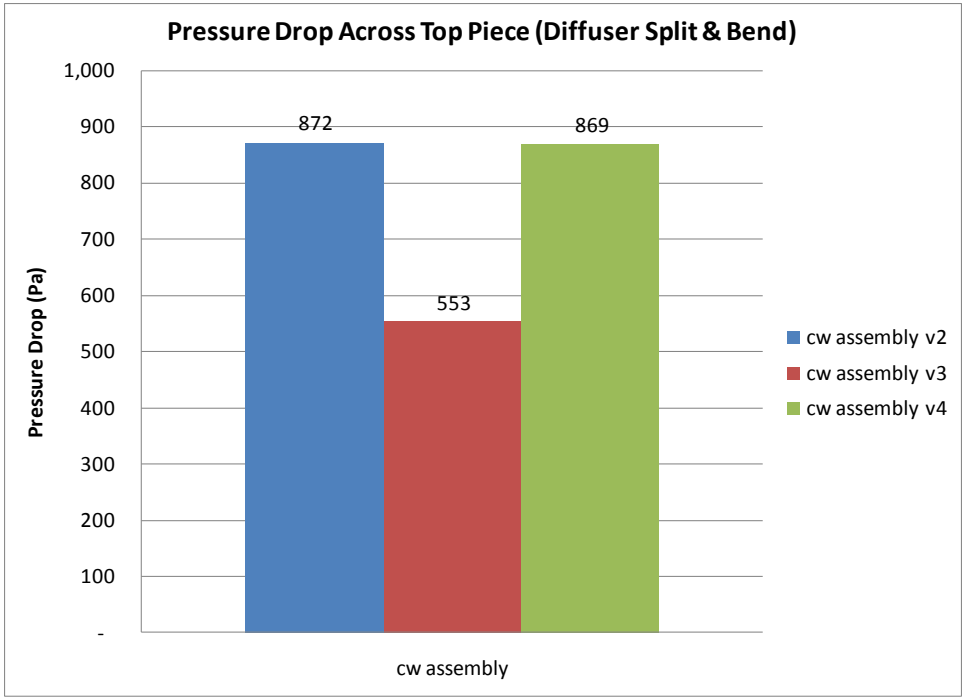


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Pressure Drop Across Top Piece (Diffuser Split & Bend)

- The pressure drop was evaluated across the top piece containing the diffuser split and bend.
  - The first plane where pressure was measured (averaged by mass flow across the plane) was taken slightly forward of the entrance to the top piece. The second plane where pressure was measured was taken at the entrance to the heat exchanger. The locations of measurement were consistent for all three assemblies
- The pressure drop was lowest for CW assembly v3.



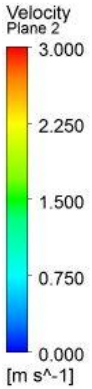


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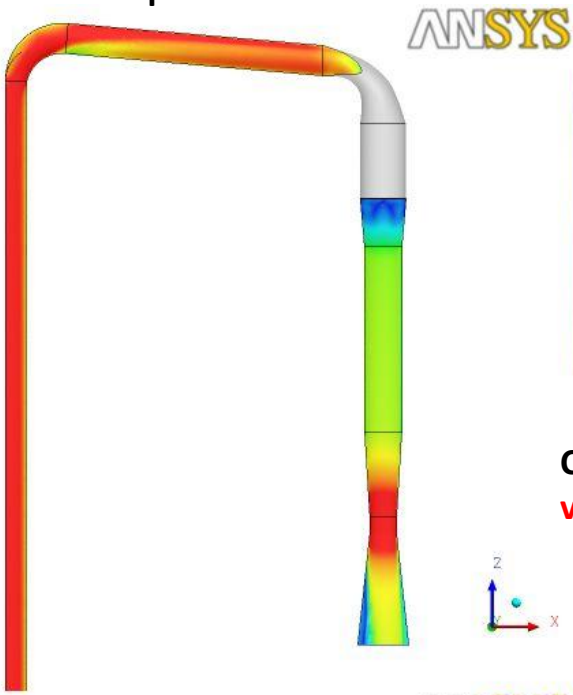
Notes on Variable Definitions

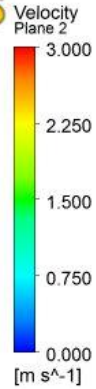
- The variable "Total Pressure" as defined in the CFX help files:
  - "The total pressure, P_{total}, is defined as the pressure that would exist at a point if the fluid was brought instantaneously to rest such that the dynamic energy of the flow converted to pressure without losses."
  - "For incompressible flows, such as those of liquids and low speed gas flows, the total pressure is given by Bernoulli's equation: $P_{total} = P_{static} + \frac{1}{2}*\rho*(\mathbf{U}\cdot\mathbf{U})$"
- The Total Pressure was converted to Total Energy per unit mass of fluid (with units of Joules/kg) using the equation: $E_{total} = P_{total} / \rho$
- Note that the Total Pressure can also be converted to total head (in meters) using: $h_{total} = P_{total} / \rho g$

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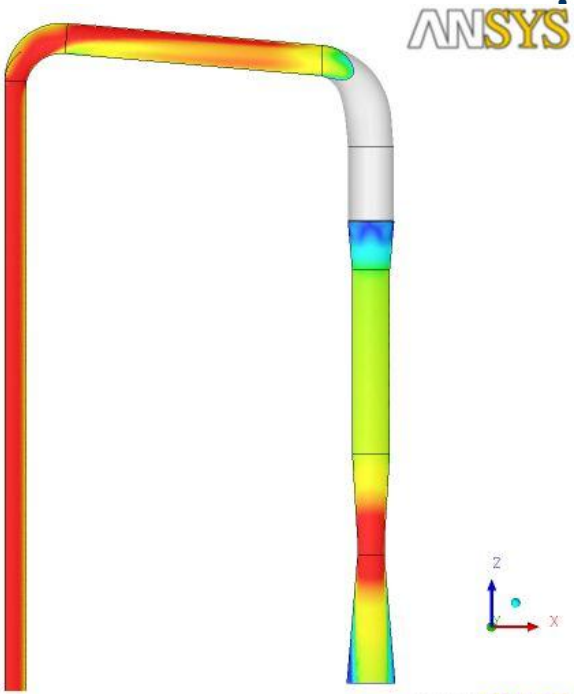


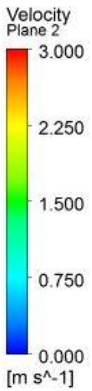
CW Assembly
v2



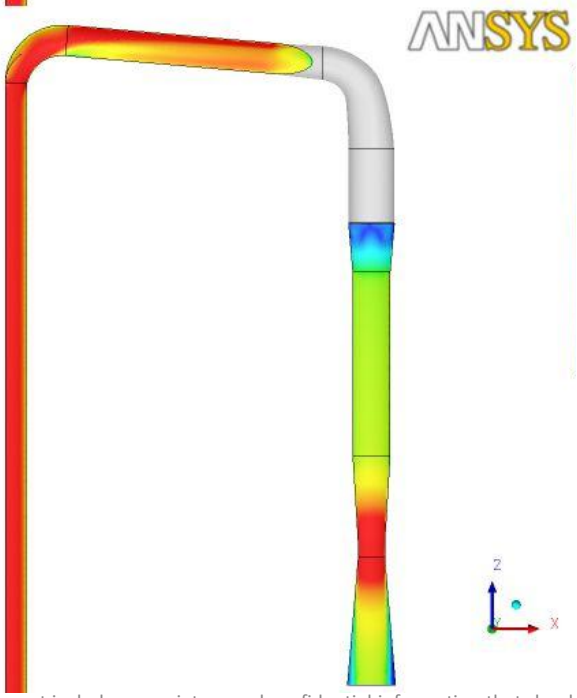


CW Assembly
v3





CW Assembly
v4



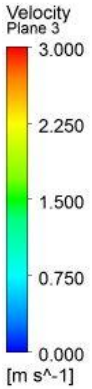
Velocity Cuts at Y=0m

(Centerline of Assembly in XZ plane)

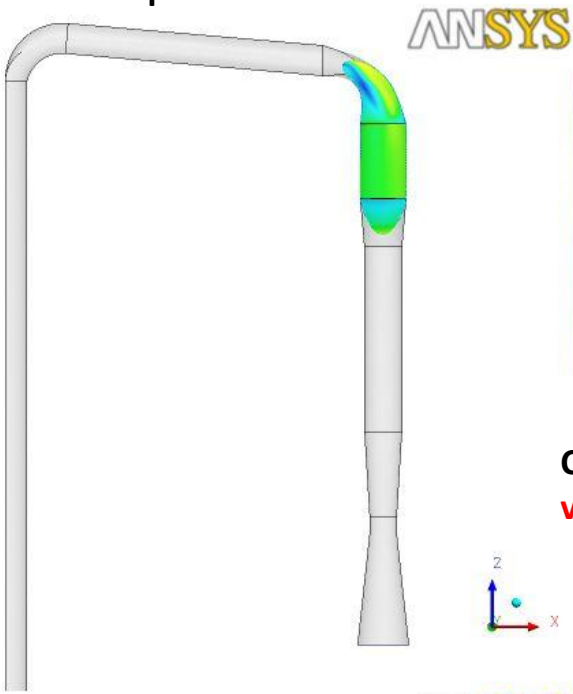
Observations:

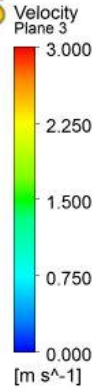
- Increase in diameter effectively slowed down flow velocity through cross-connect duct and top piece in CW assembly v3 and v4.
- Flow at discharge of CW assembly improved for CW assembly v3 and v4. There is less recirculation, and flow profile is more uniform (see also Slide 19).

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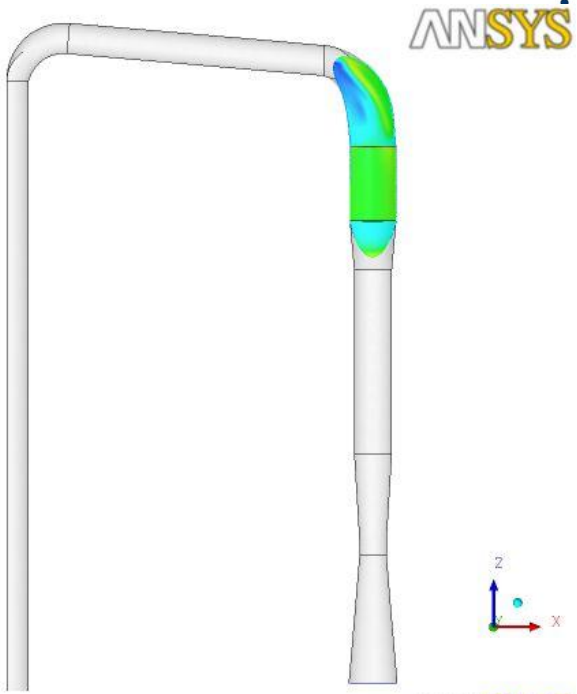


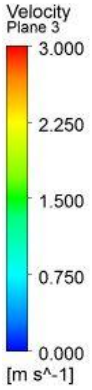
CW Assembly
v2



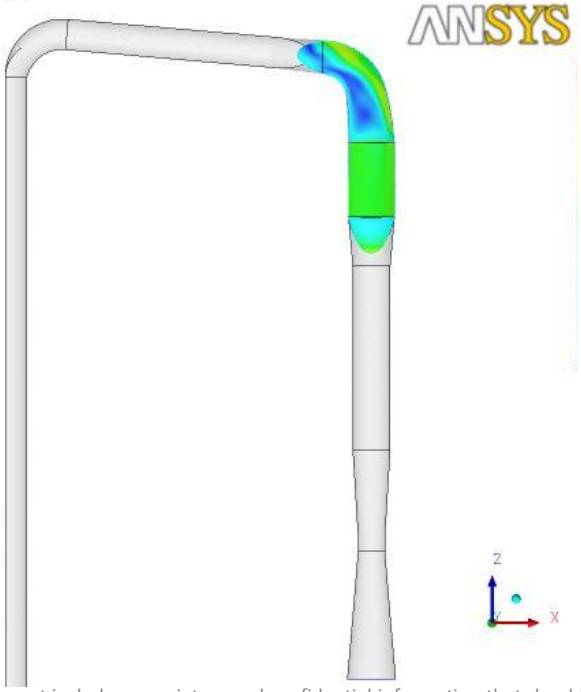


CW Assembly
v3





CW Assembly
v4



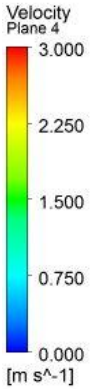
Velocity Cuts at Y=2.5m

(Centerline of HX in XZ plane)

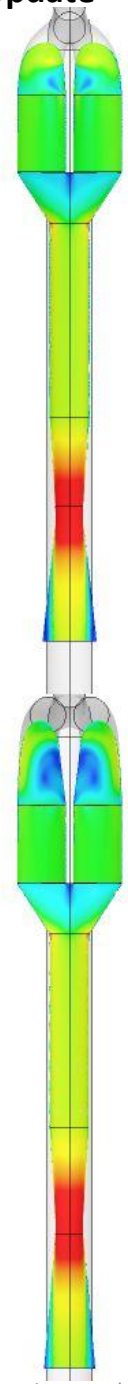
Observations:

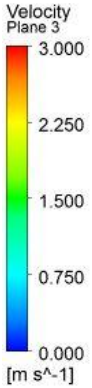
- Flow in the top piece slows down a greater amount in v3 compared to v2, and more so in v4 of the CW assembly.

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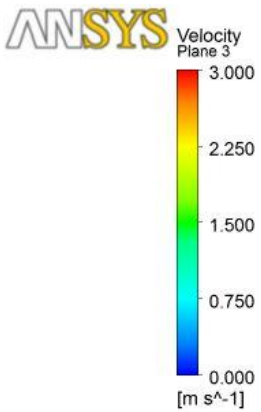


CW Assembly
v2

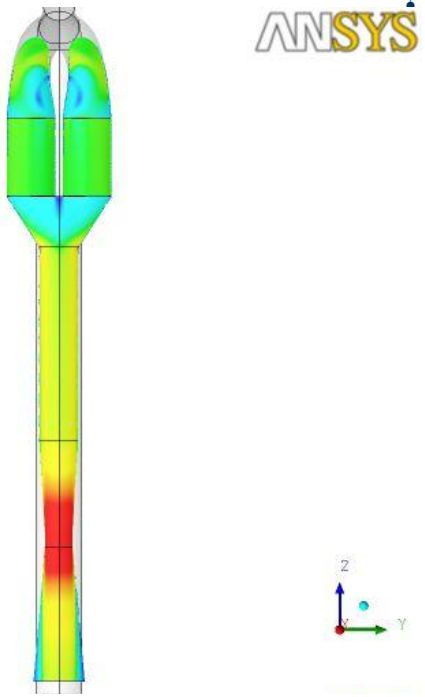




CW Assembly
v4



CW Assembly
v3

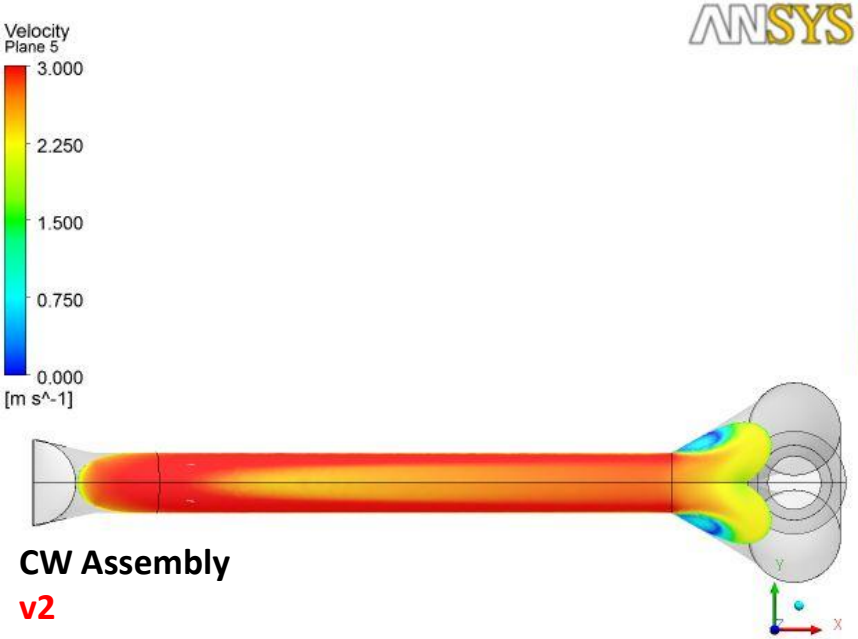




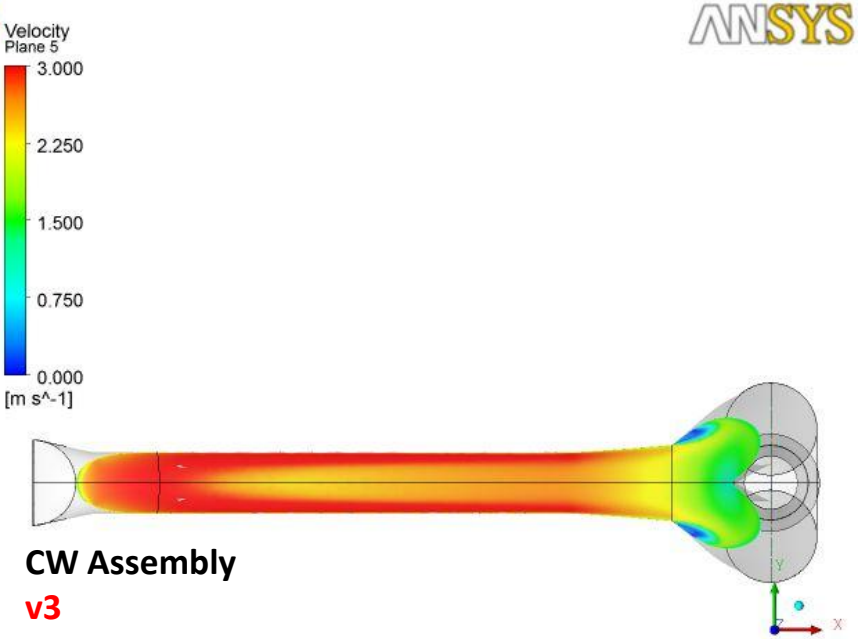
Velocity Cuts at X=35.5m (v2), X=34.4m (v3 & v4)

(Centerline of HX in YZ plane)

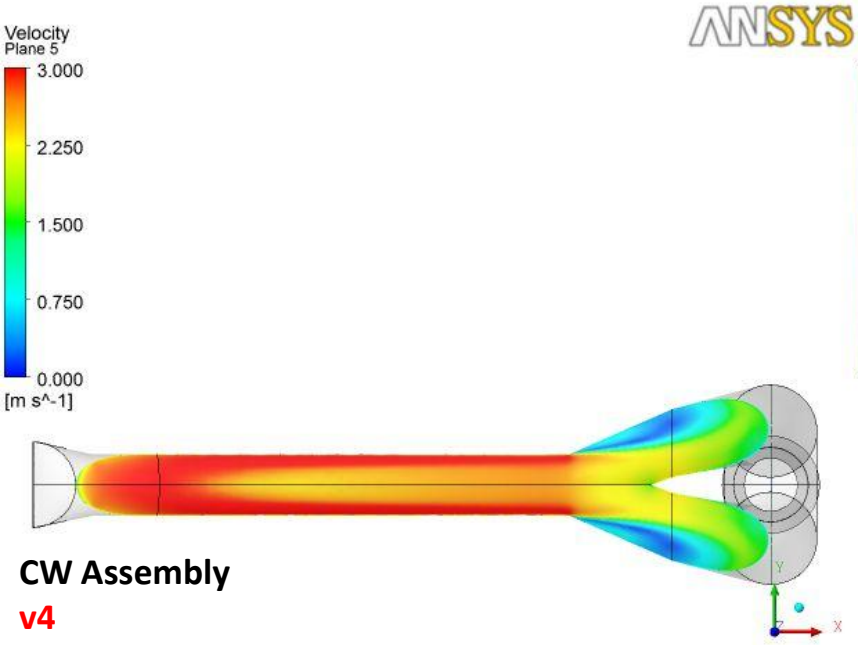
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CW Assembly
v2



CW Assembly
v3



CW Assembly
v4

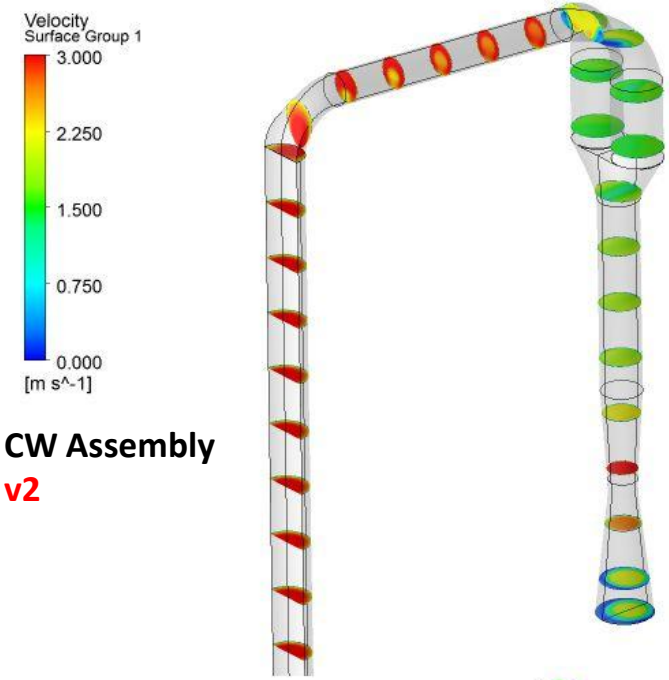
Velocity Cuts in Plane of Cross-Connect Duct, Viewed Normal to XY Plane

(Centerline of cross-connect duct in plane parallel to direction of flow in cross-connect duct)

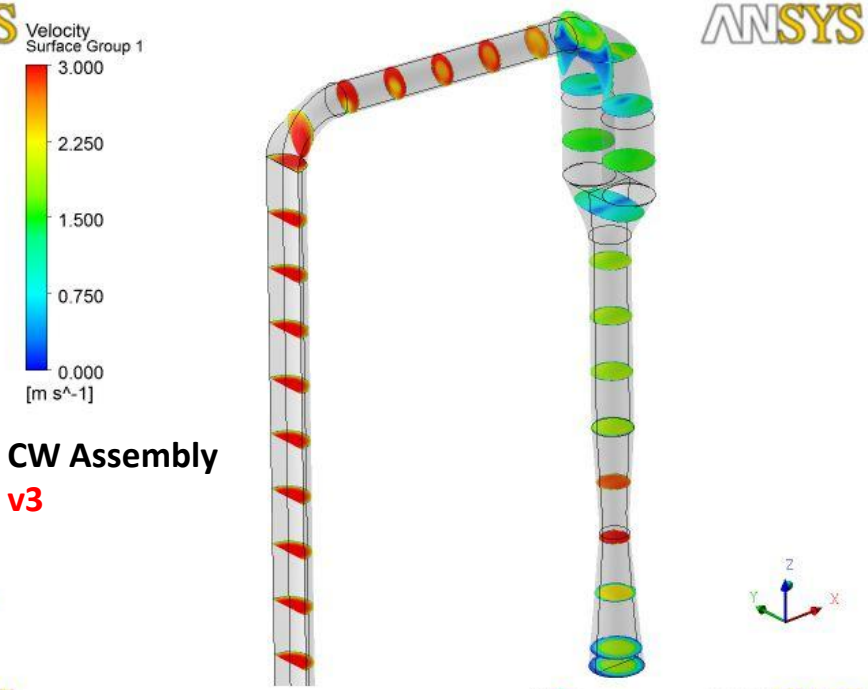
Observations:

- Greater amount of flow separation leading into the top piece can be observed in CW assembly v4, and less in v3.

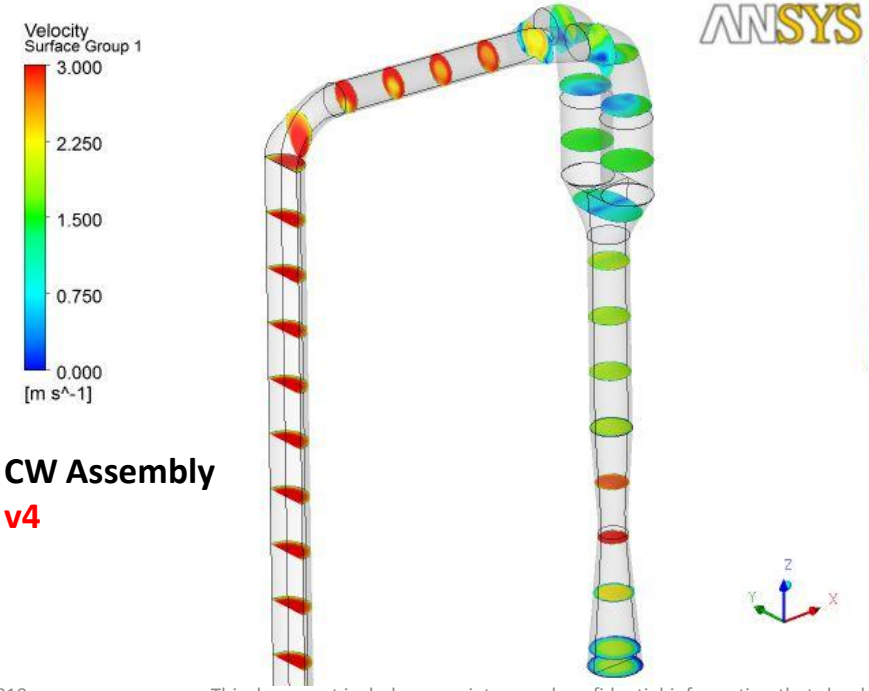
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CW Assembly
v2



CW Assembly
v3

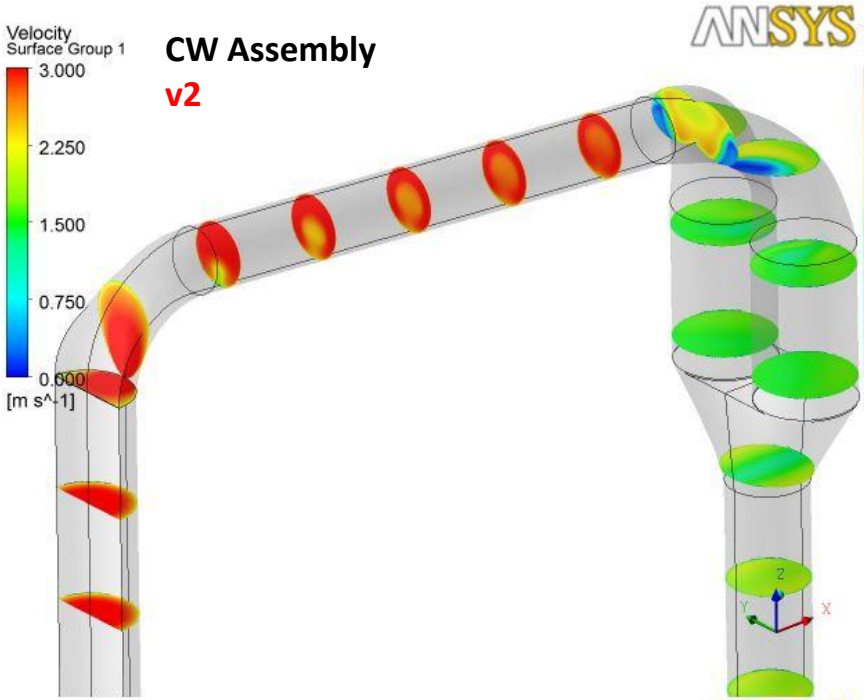


CW Assembly
v4

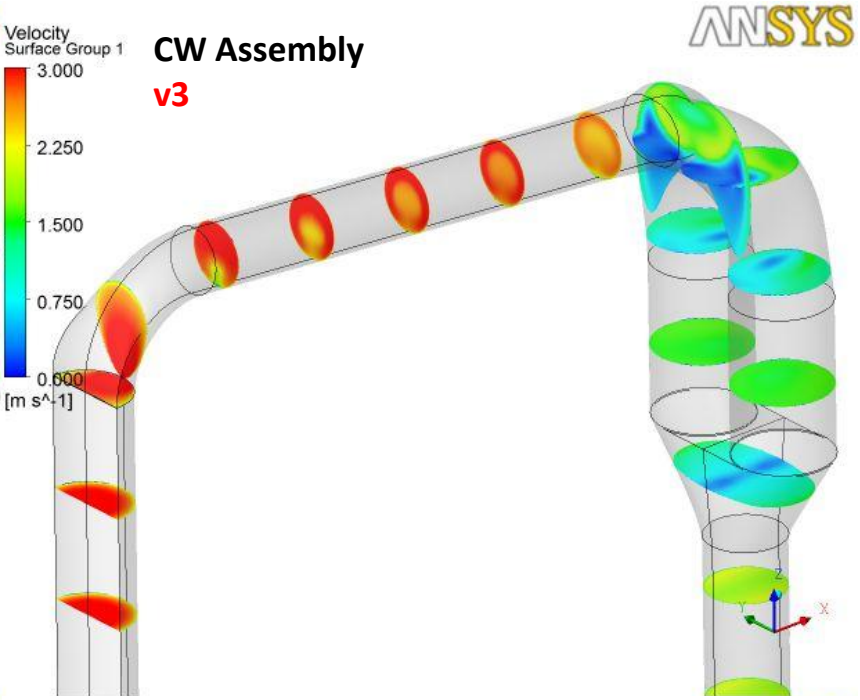
Velocity Cuts

(In X and Z every ~5 m)

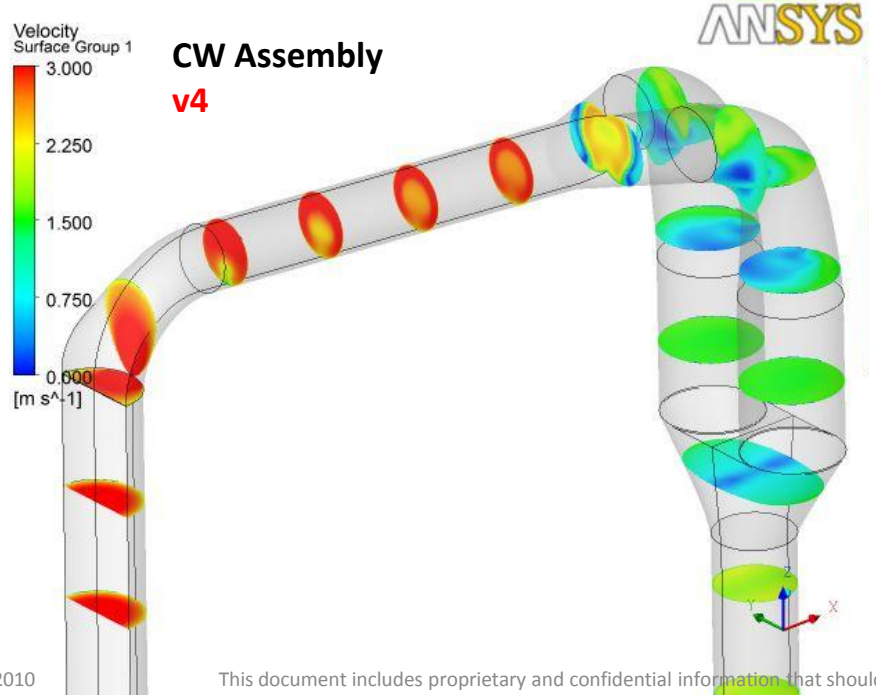
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CW Assembly
v2



CW Assembly
v3

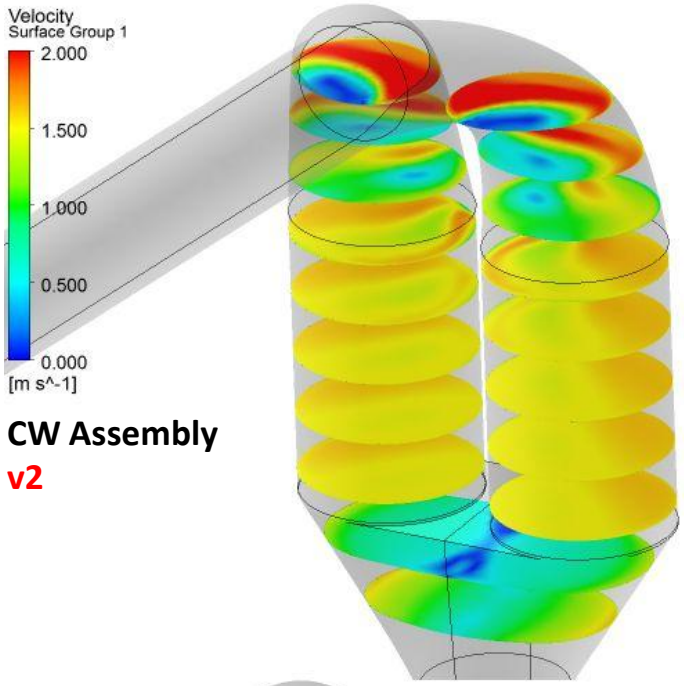


CW Assembly
v4

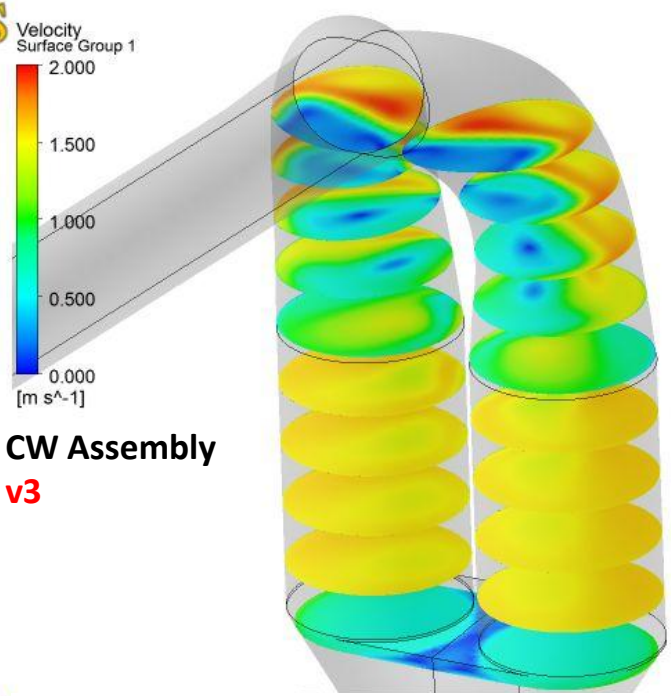
Velocity Cuts

(In X and Z every ~5 m)

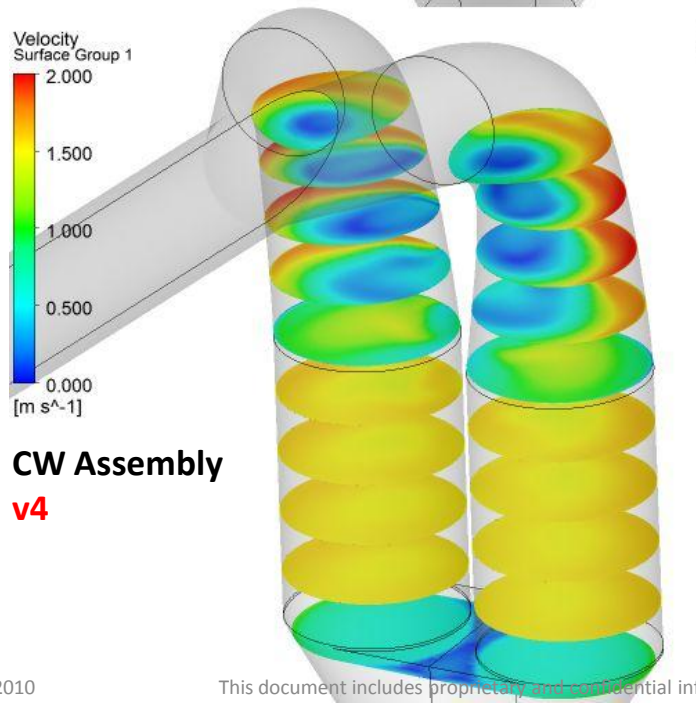
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CW Assembly
v2



CW Assembly
v3



CW Assembly
v4

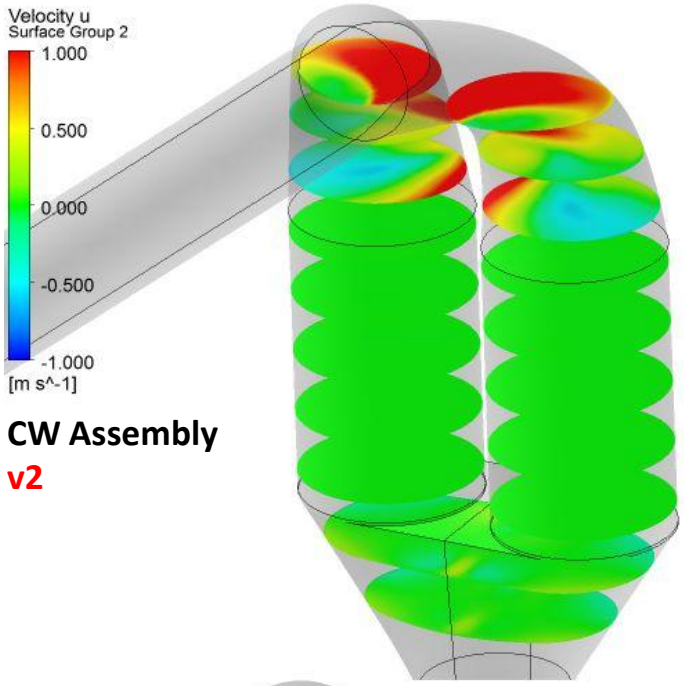
HX Velocity Cuts

(In Z every ~1.5 m)

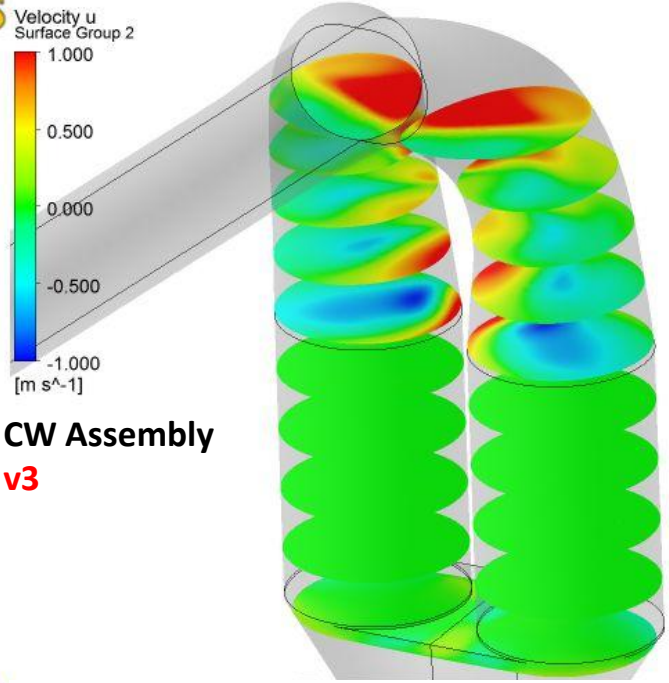
Observations:

- Although flow is still not uniform through the heat exchanger, uniformity seems to have improved slightly in CW assembly v4 due to slow-down of the flow.

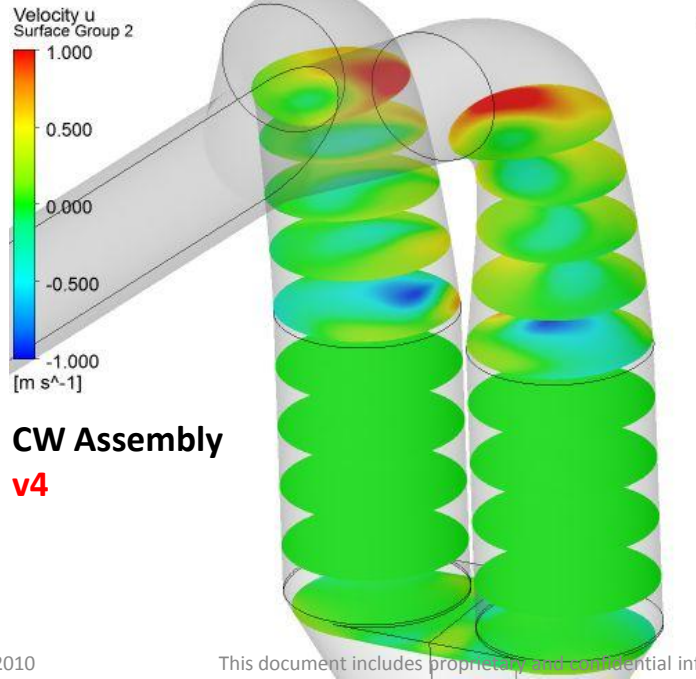
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CW Assembly
v2



CW Assembly
v3

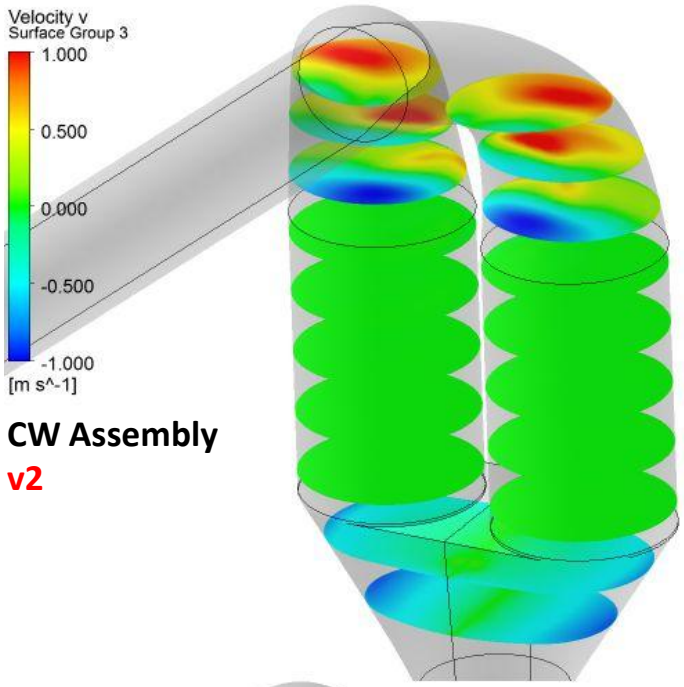


CW Assembly
v4

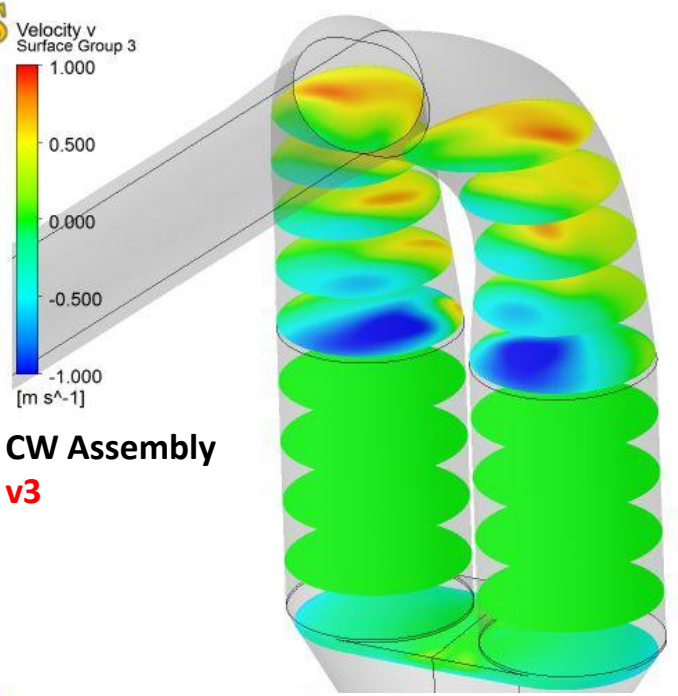
HX Velocity Cuts in U

(In Z every ~1.5 m)
Note: direction of flow into the paper is positive, out of the paper is negative

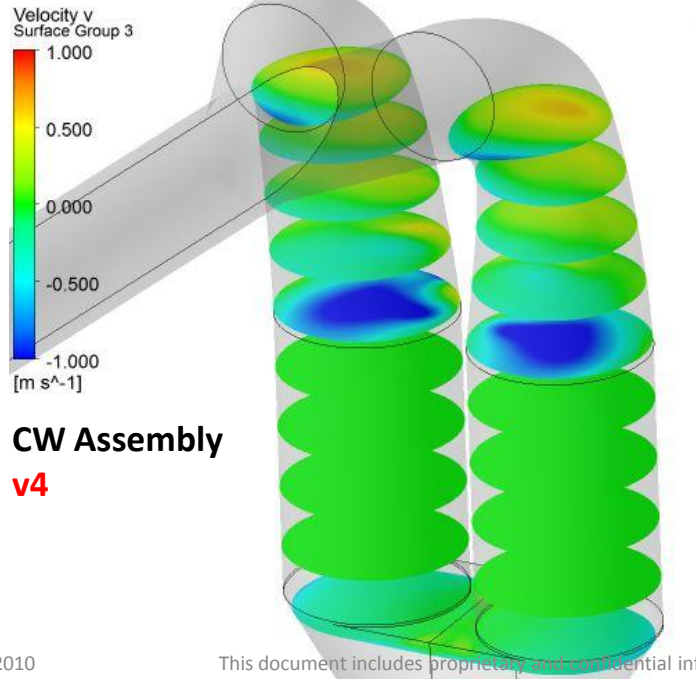
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CW Assembly
v2



CW Assembly
v3



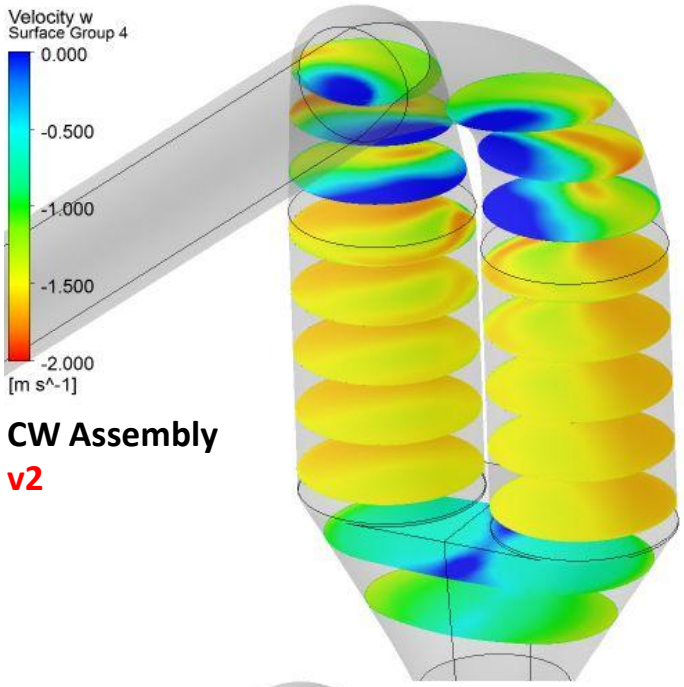
CW Assembly
v4

HX Velocity Cuts in V

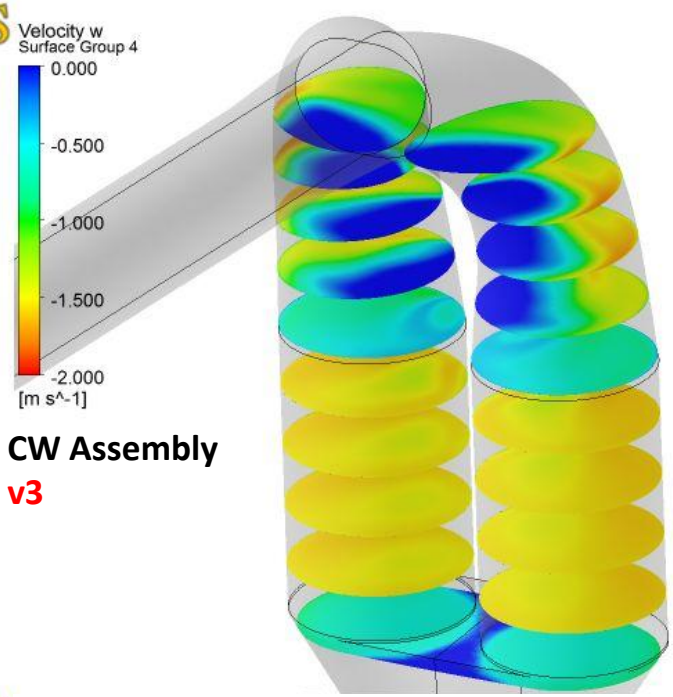
(In Z every ~1.5 m)

Note: only half of the CW assembly was meshed (the half on the positive-Y, or left side looking at this image), and a symmetry plane defined in the solver to model the other half. The screenshots were created by selecting a mirror image to be shown in the post-processor. Thus, the mirrored (right) half for this image should be opposite in color, ranging from -1 m/s as red to +1 m/s as blue.

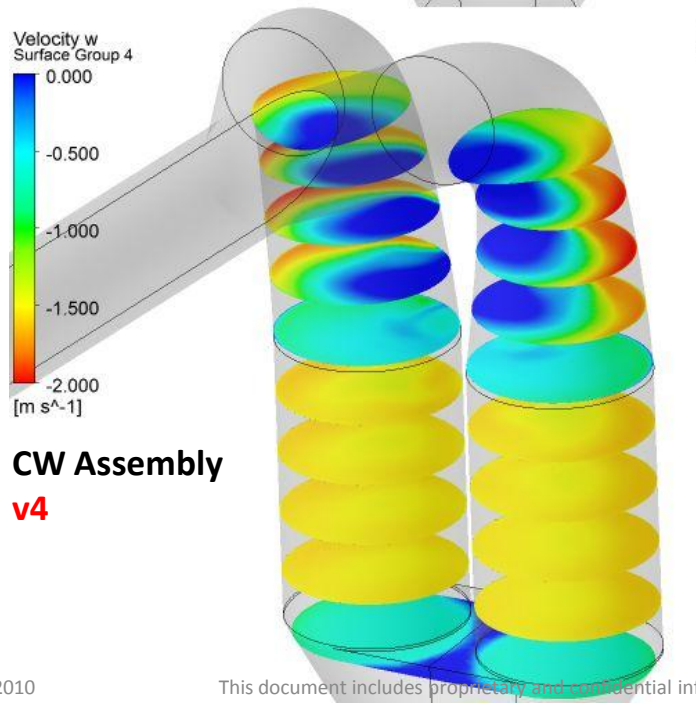
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CW Assembly
v2



CW Assembly
v3



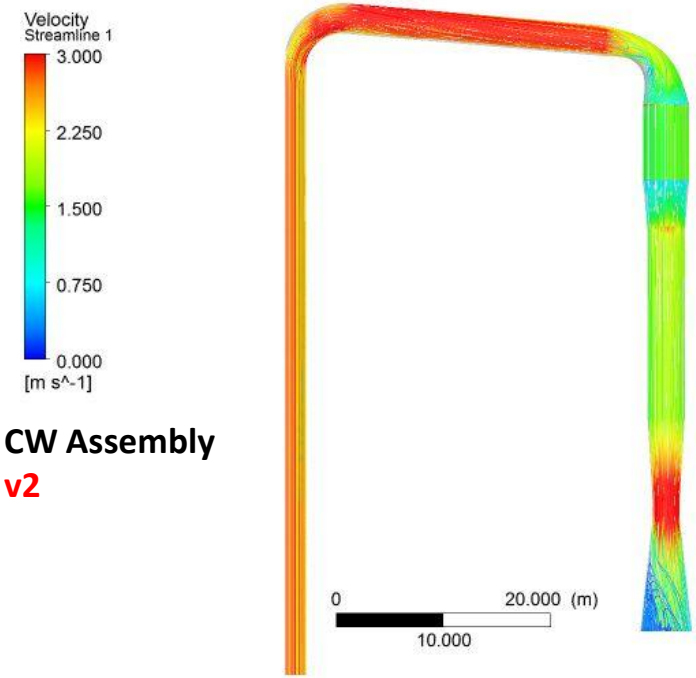
CW Assembly
v4

HX Velocity Cuts in W

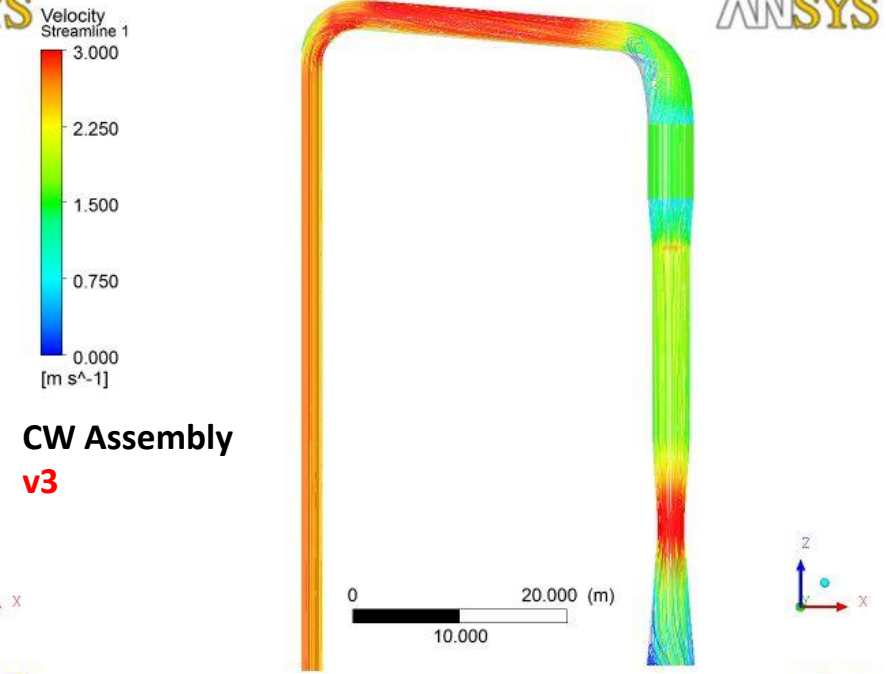
(In Z every 1.5 m)

Note: up is positive, down is negative

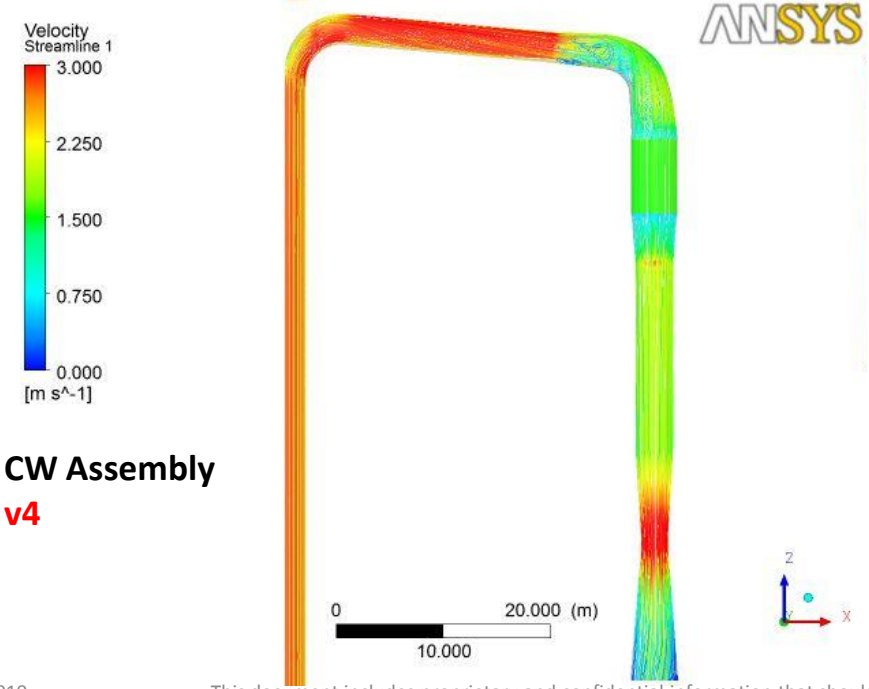
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CW Assembly
v2



CW Assembly
v3



CW Assembly
v4

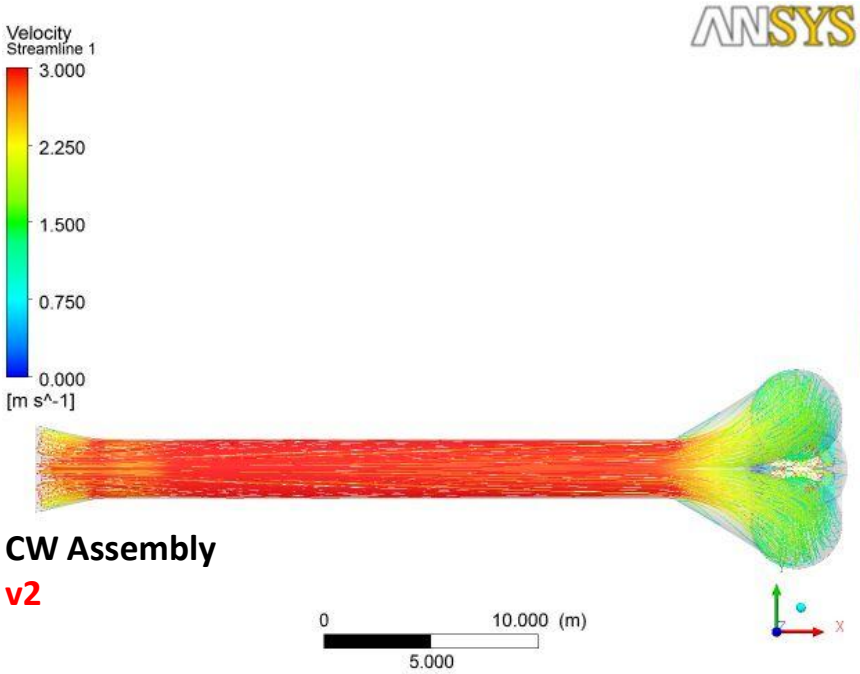
Velocity Streamlines

(View normal to XZ plane)

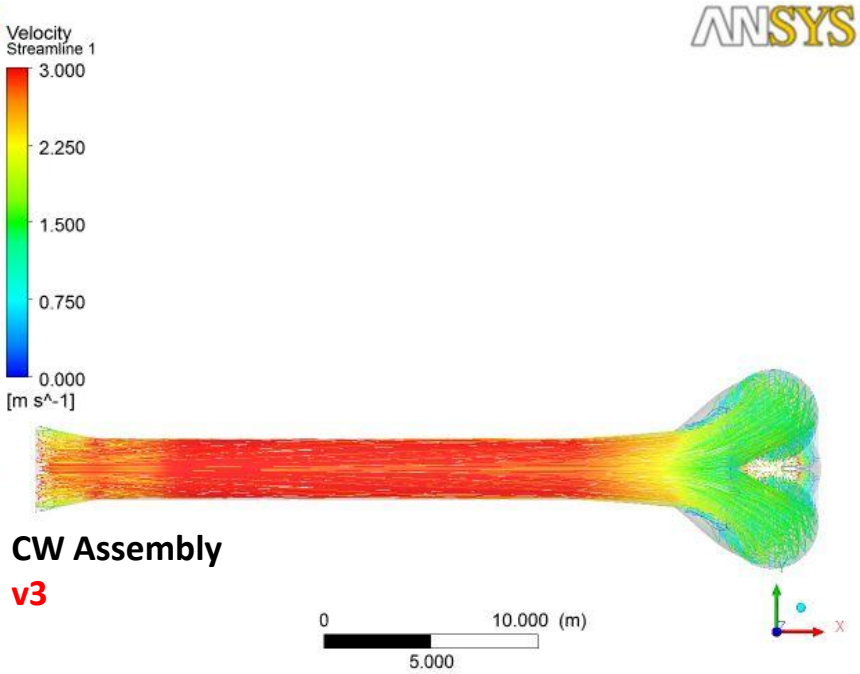
Observations:

- Flow at CW assembly discharge improved slightly for CW assembly v3, and greatly for CW assembly v4. There is less recirculation, and flow profile is more uniform (see also slide 9).

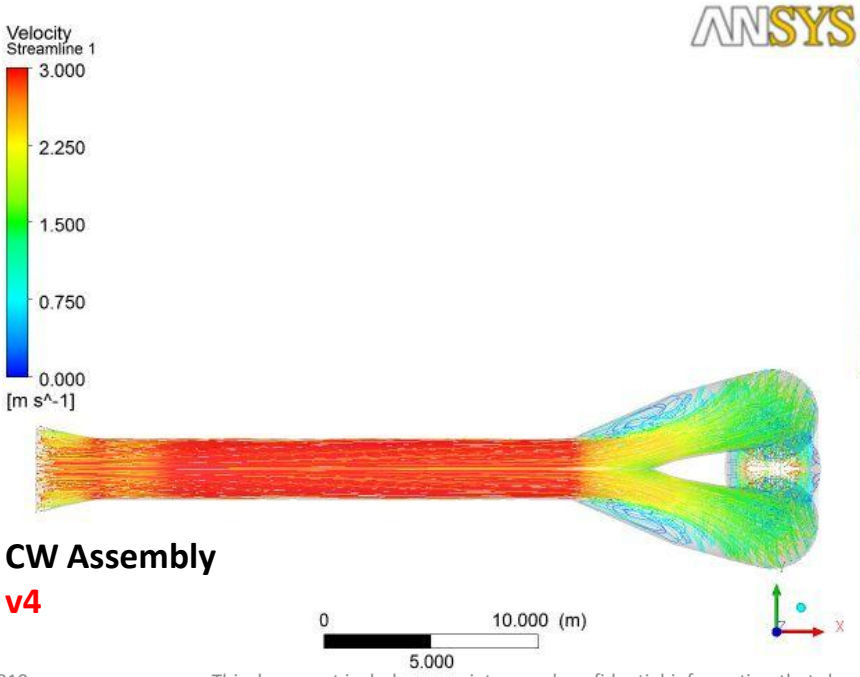
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CW Assembly
v2



CW Assembly
v3

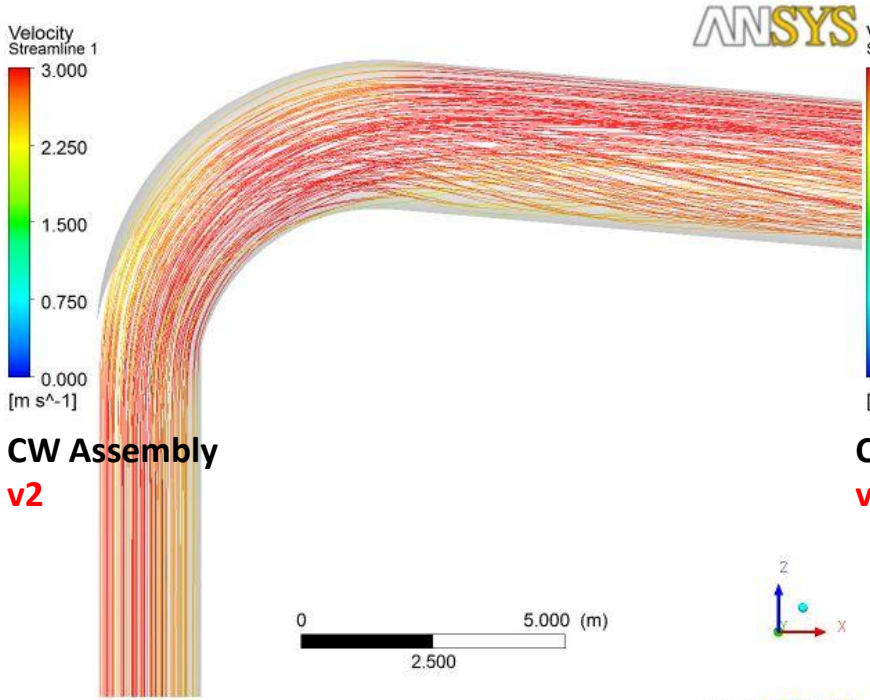


CW Assembly
v4

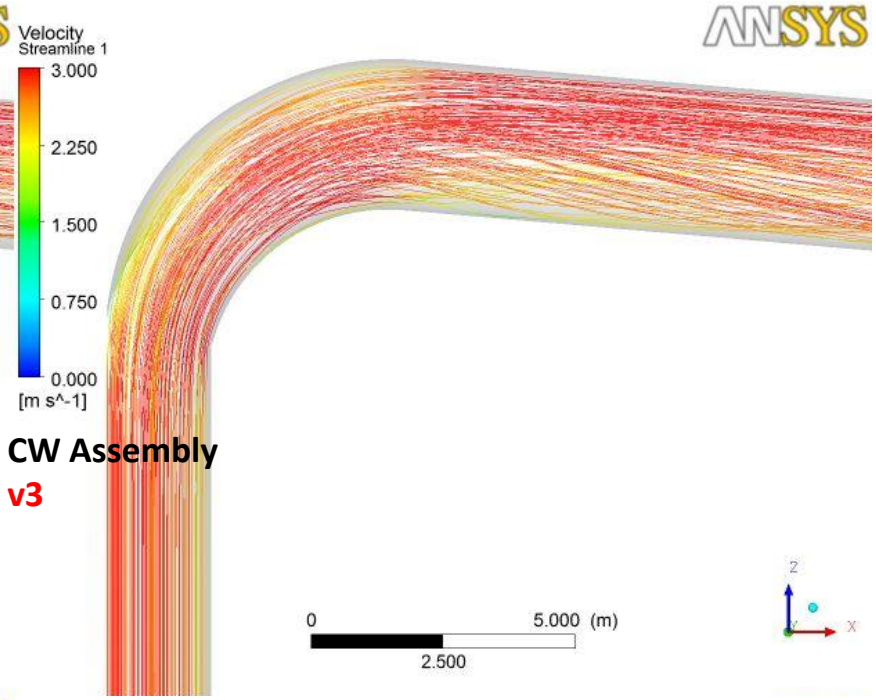
Velocity Streamlines

(View normal to XY plane)

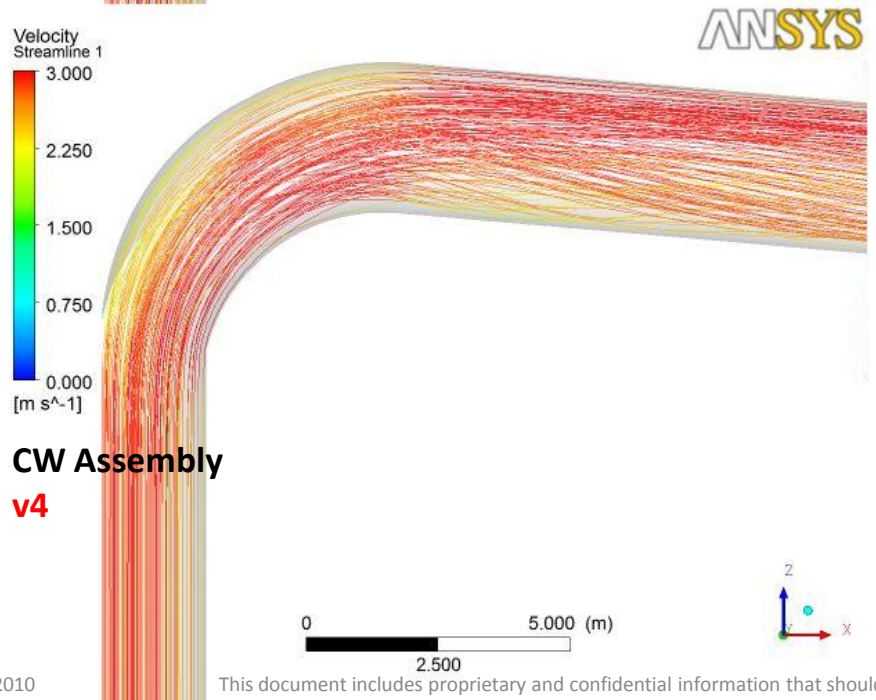
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CW Assembly
v2



CW Assembly
v3

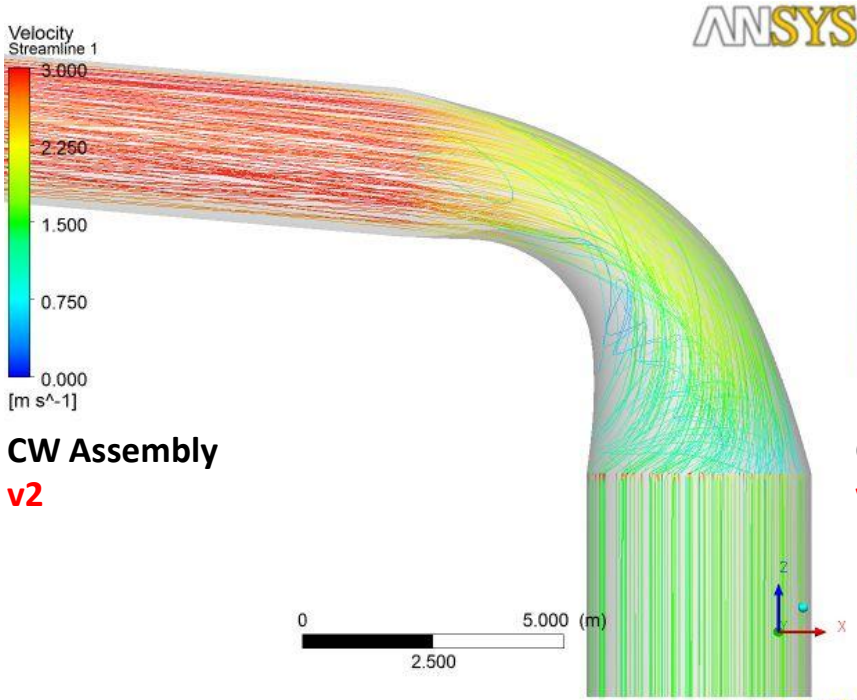


CW Assembly
v4

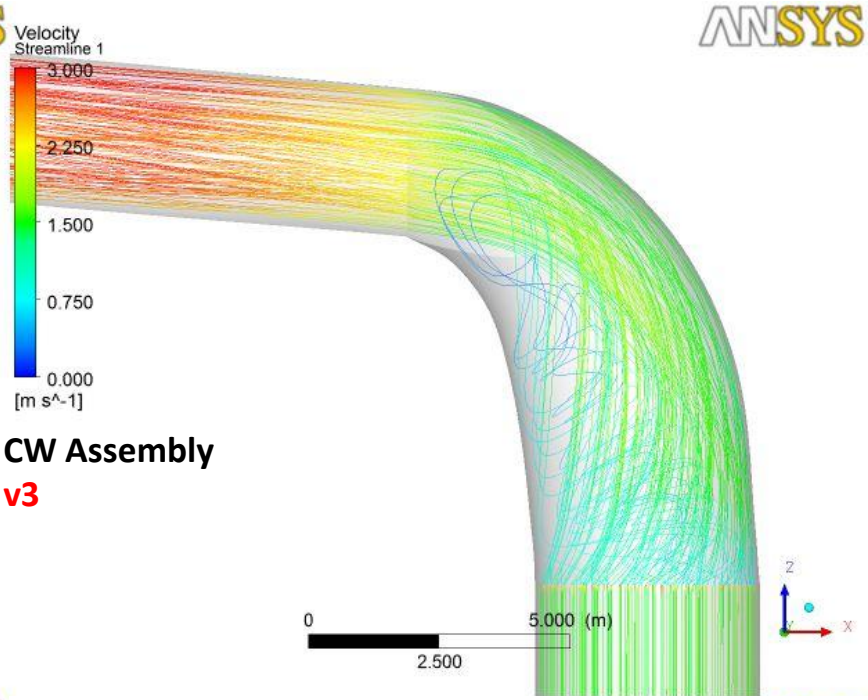
Velocity Streamlines

(View normal to XZ plane, close-up of bend leading to cross-connect duct)

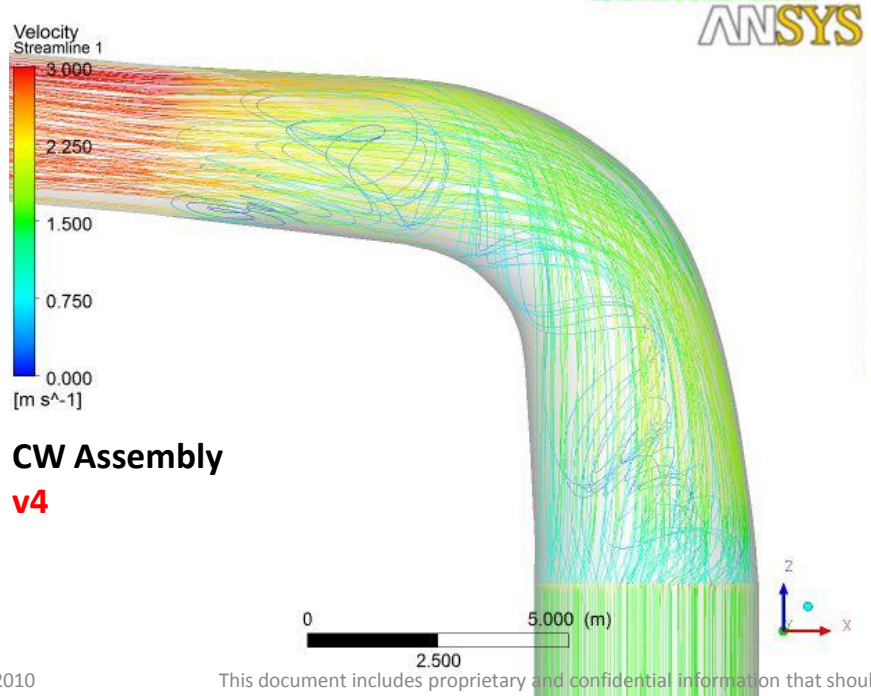
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CW Assembly
v2



CW Assembly
v3

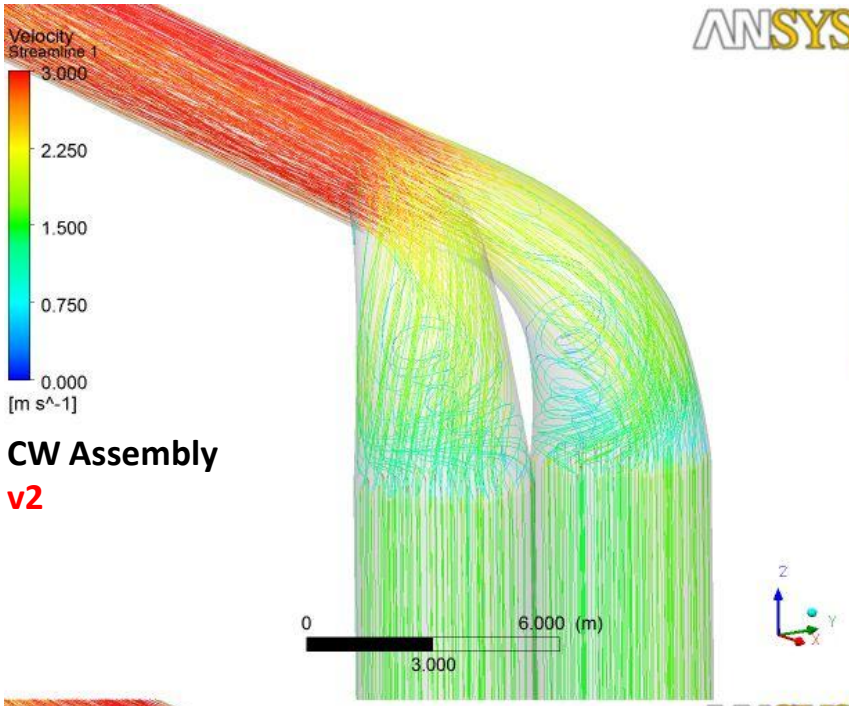


CW Assembly
v4

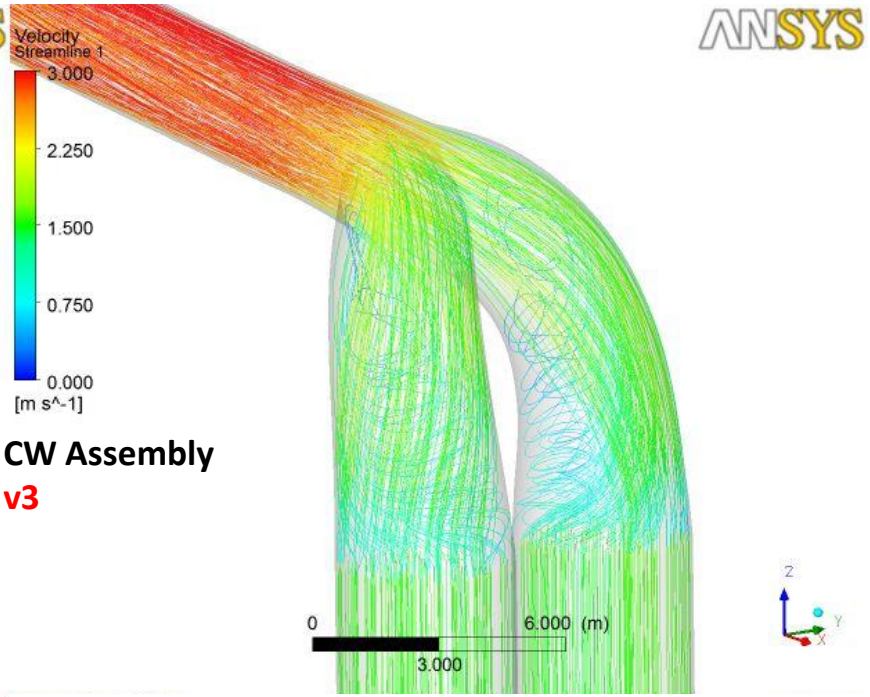
Velocity Streamlines

(View normal to XZ plane, close-up of split and bend leading to heat exchanger)

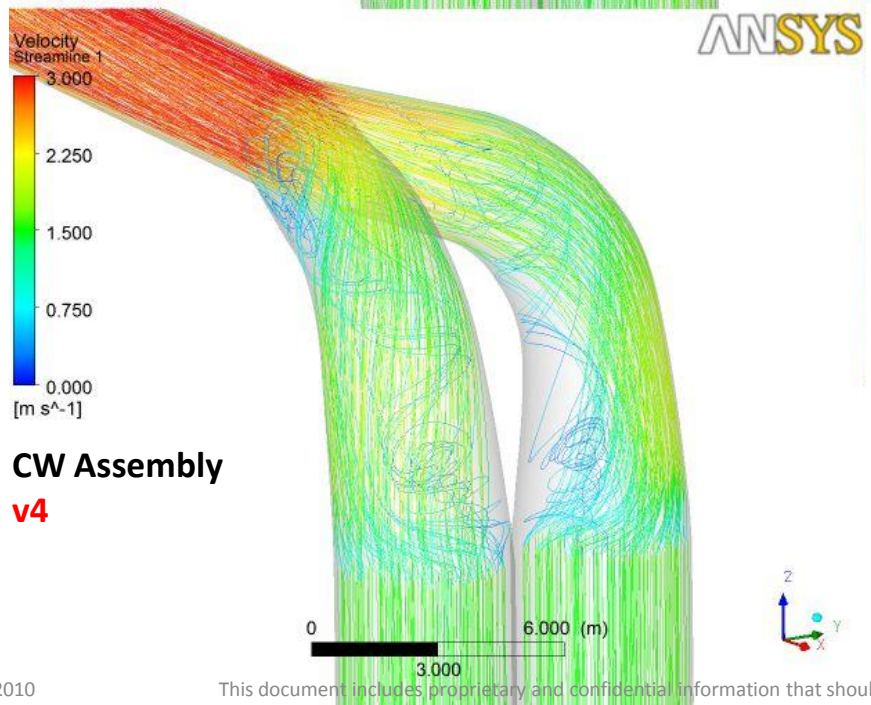
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CW Assembly
v2



CW Assembly
v3

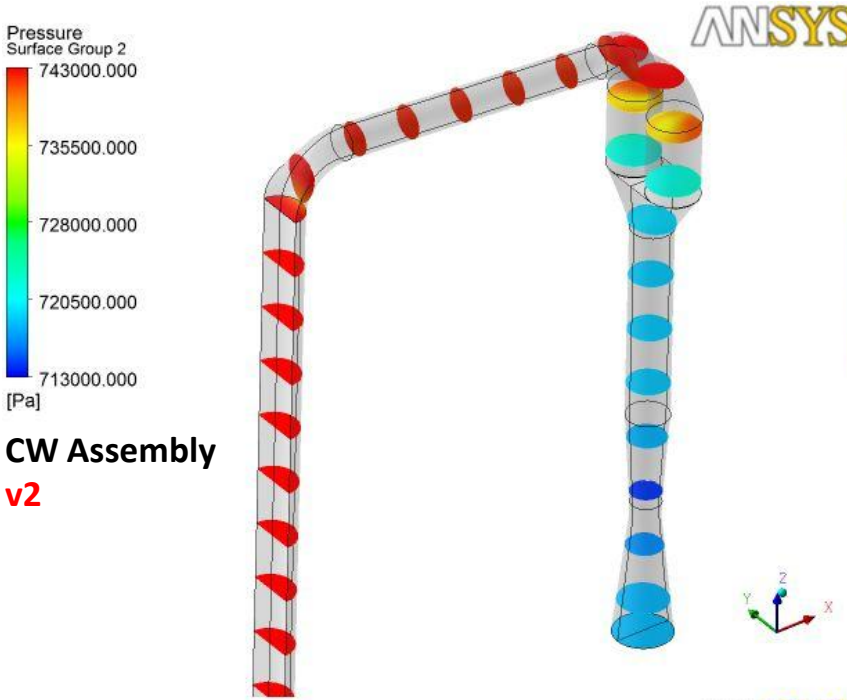


CW Assembly
v4

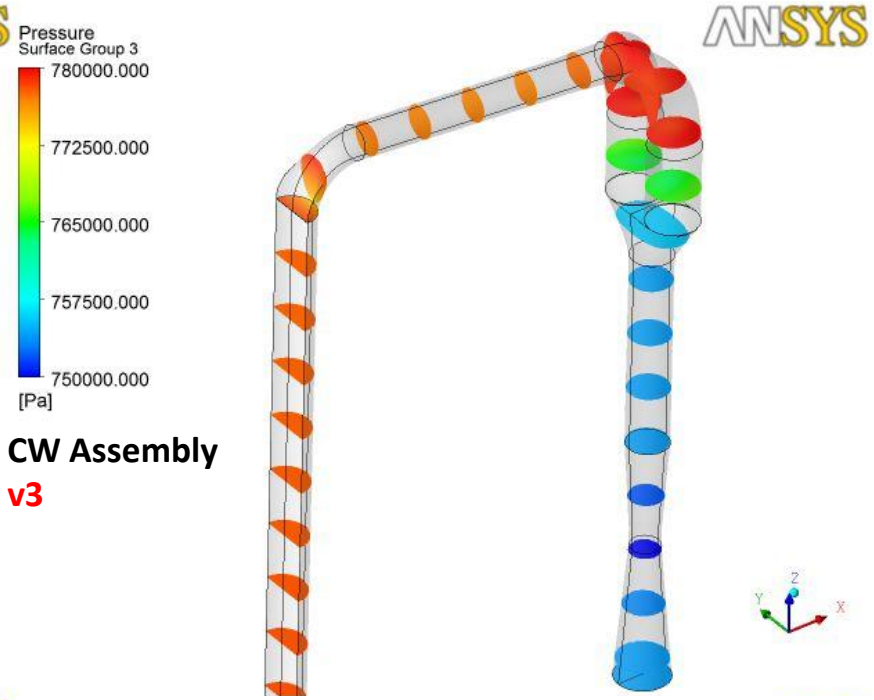
Velocity Streamlines

(3D view, close-up of split and bend leading to heat exchanger)

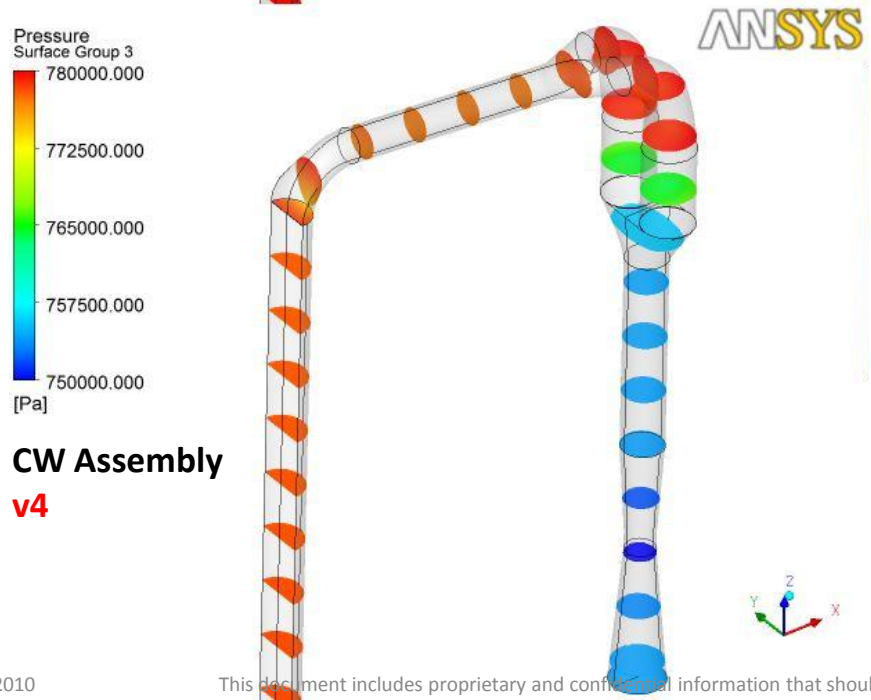
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CW Assembly
v2



CW Assembly
v3

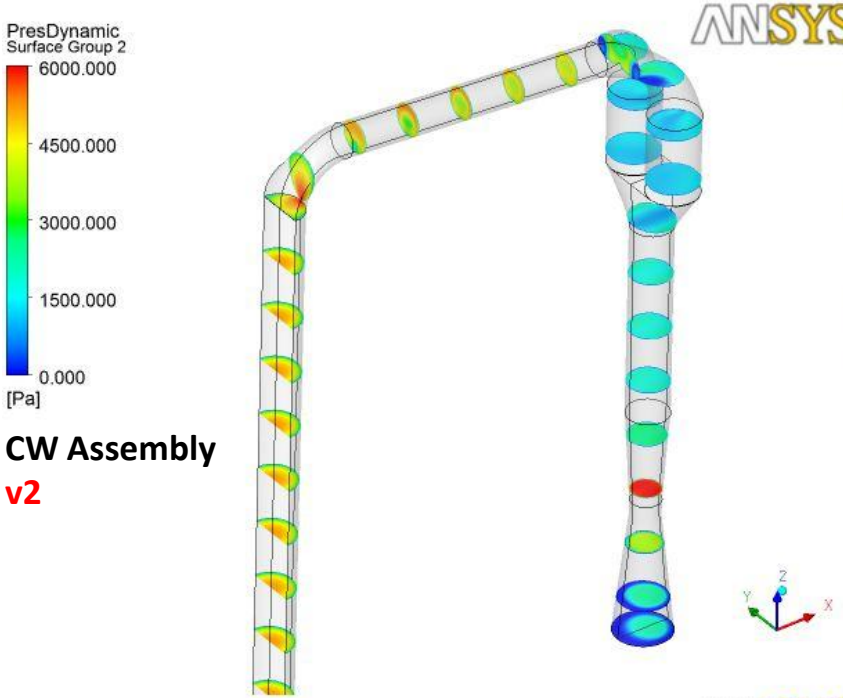


CW Assembly
v4

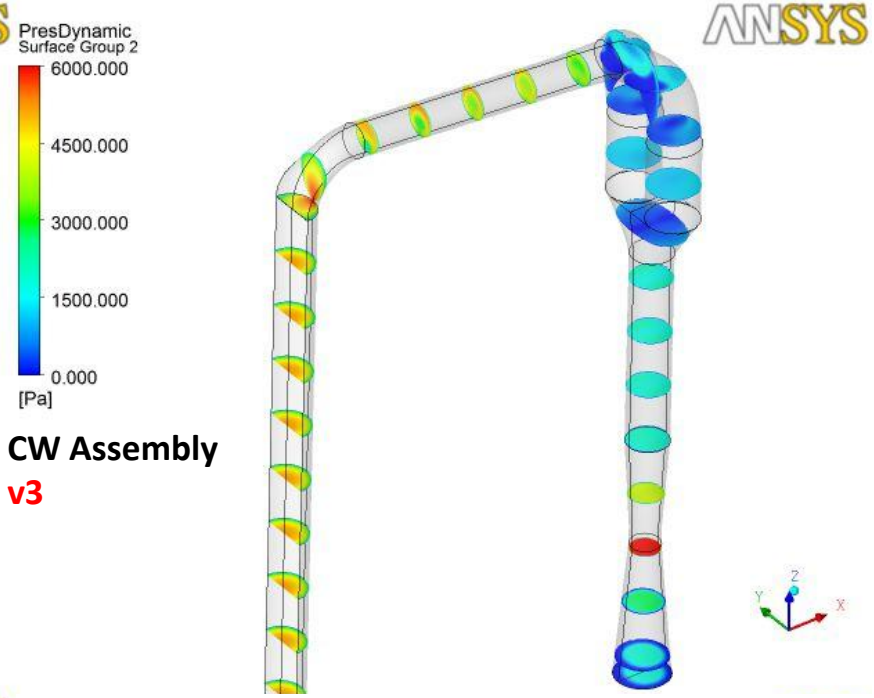
Pressure Cuts: Static Component

(In X and Z every ~5 m)

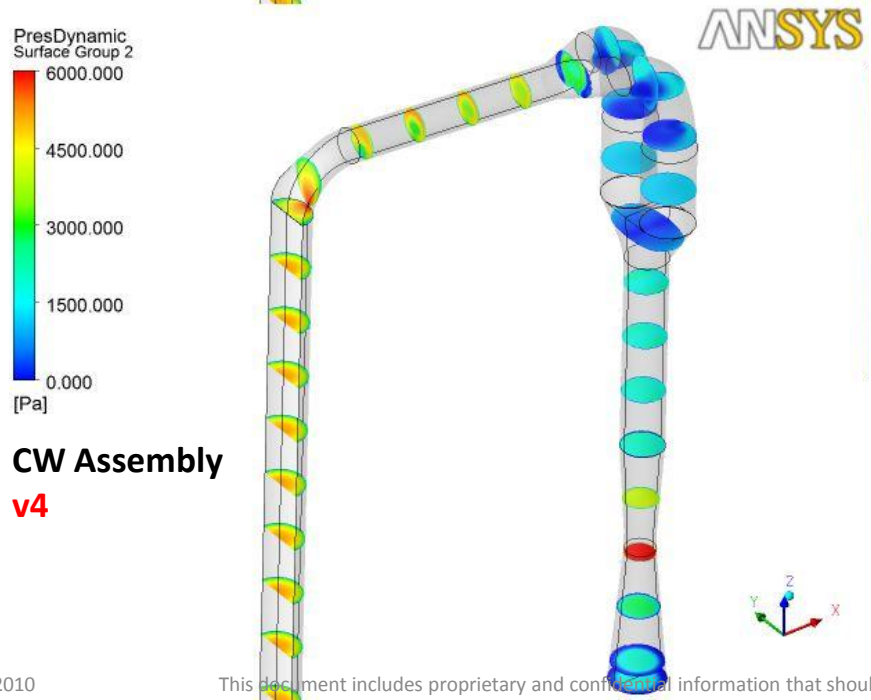
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CW Assembly
v2



CW Assembly
v3

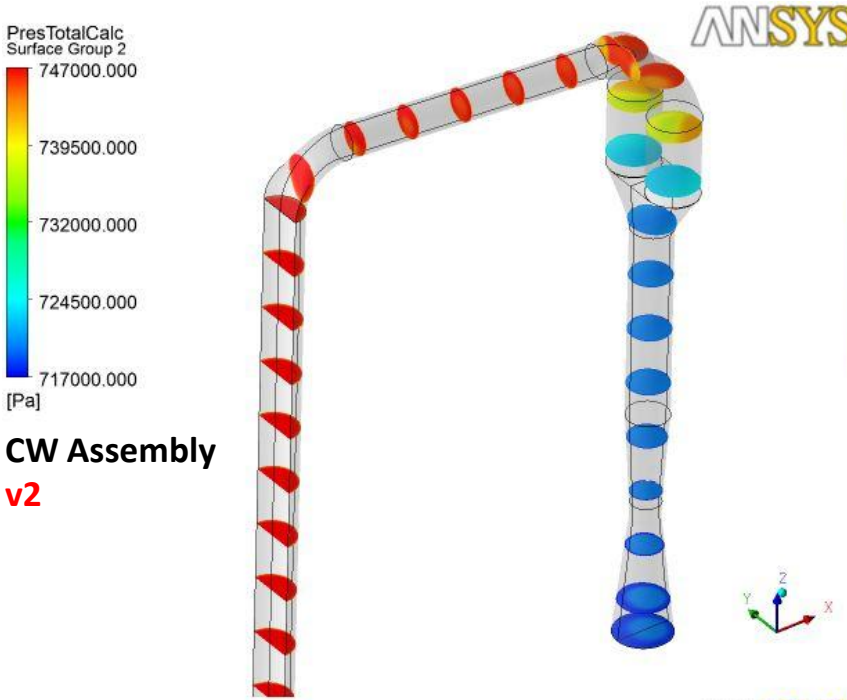


CW Assembly
v4

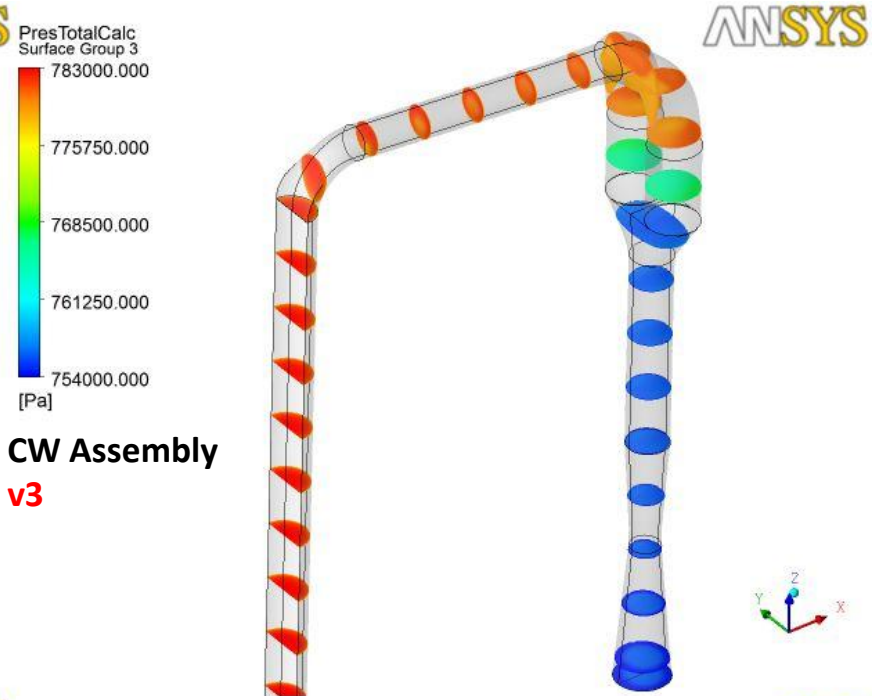
Pressure Cuts: Dynamic Component ($1/2*\rho*v^2$)

(In X and Z every ~5 m)

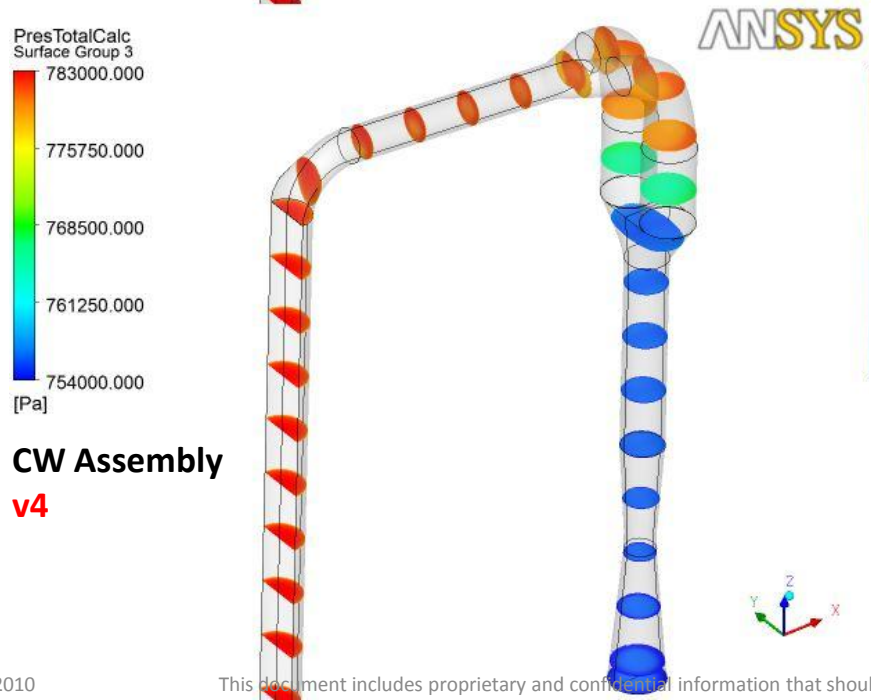
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CW Assembly
v2



CW Assembly
v3

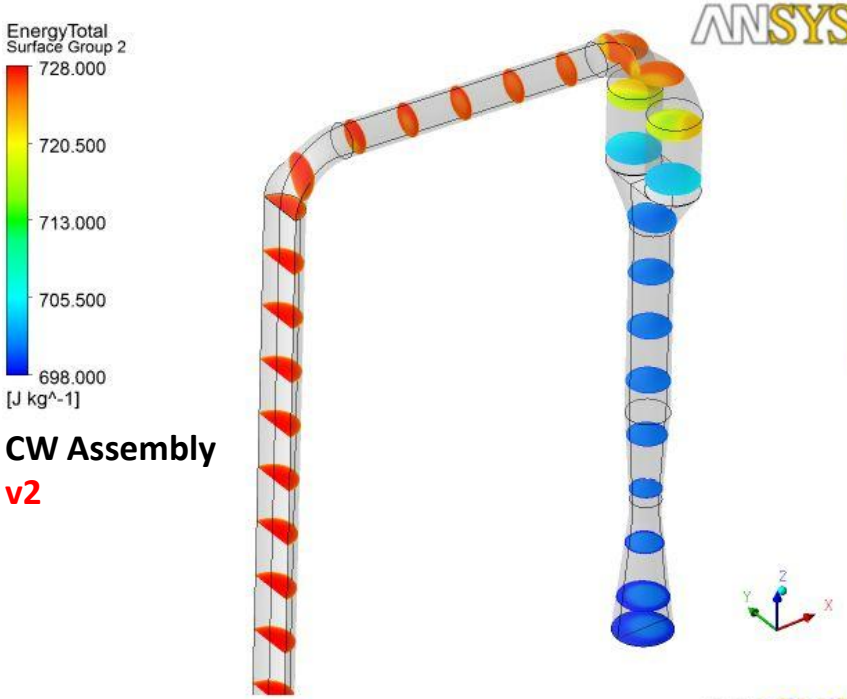


CW Assembly
v4

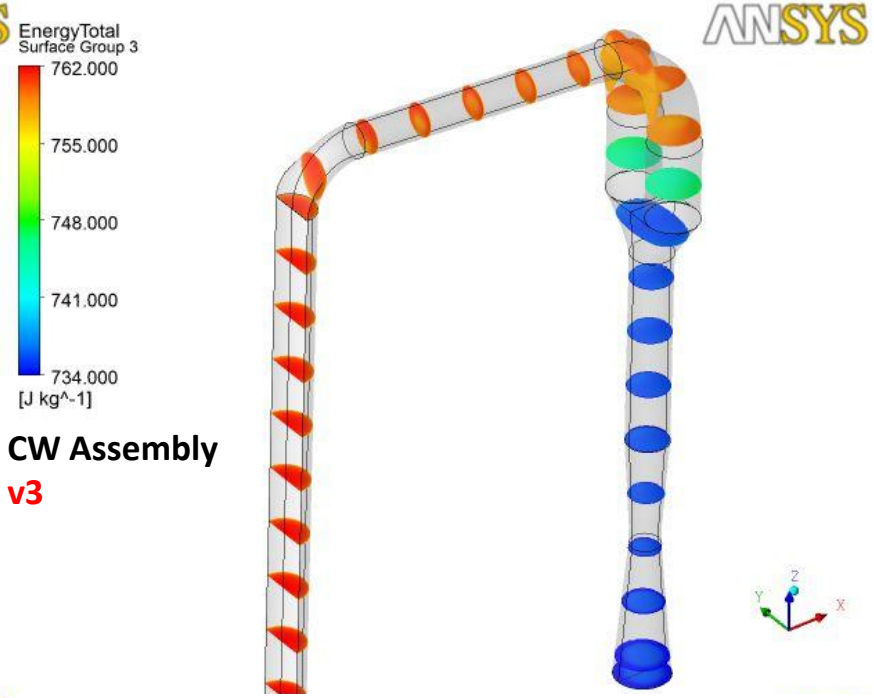
Total Pressure Cuts: Static + Dynamic Components

(In X and Z every ~5 m)

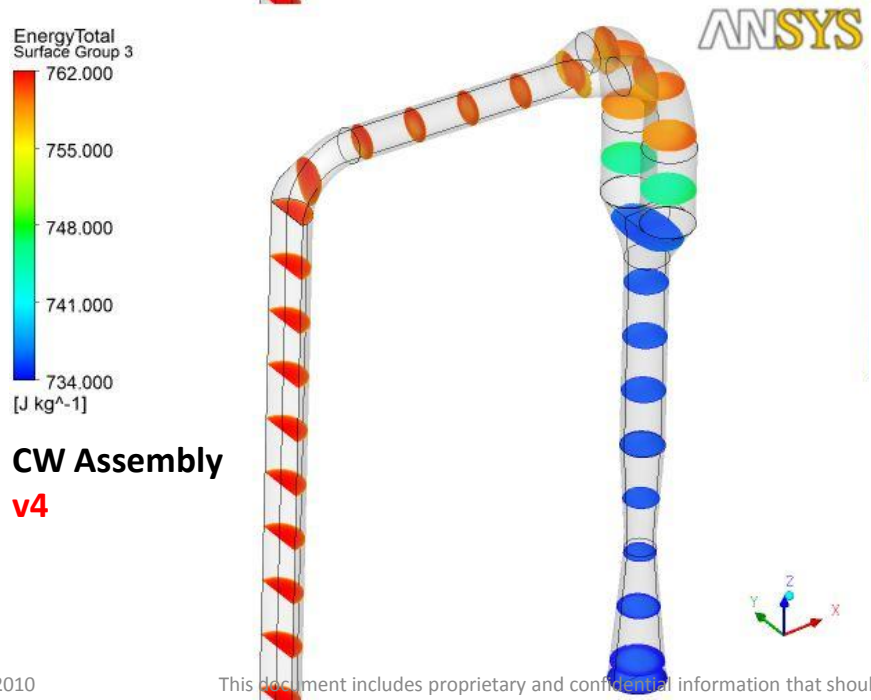
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CW Assembly
v2



CW Assembly
v3

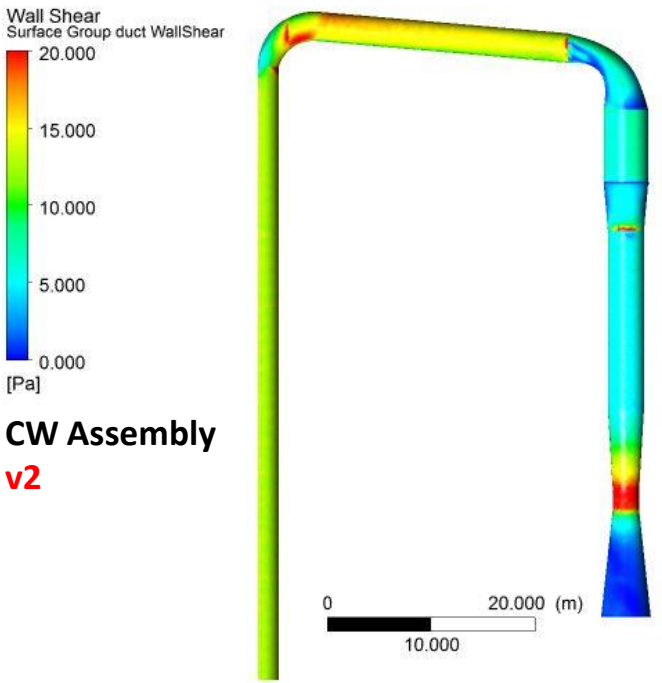


CW Assembly
v4

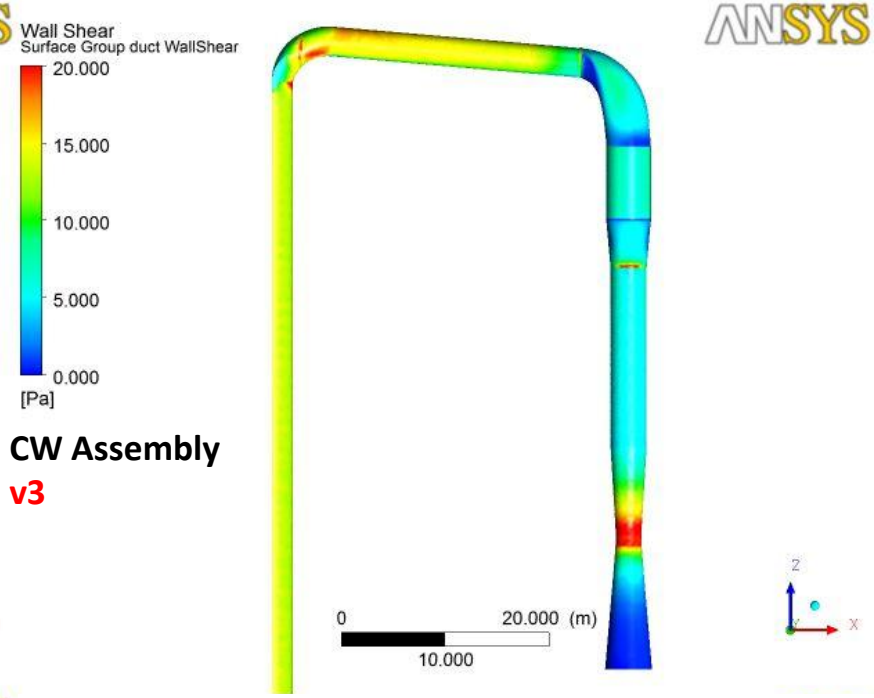
Total Energy per Unit Mass Cuts: Converted from Total Pressure (E = P/ρ)

(In X and Z every ~5 m)

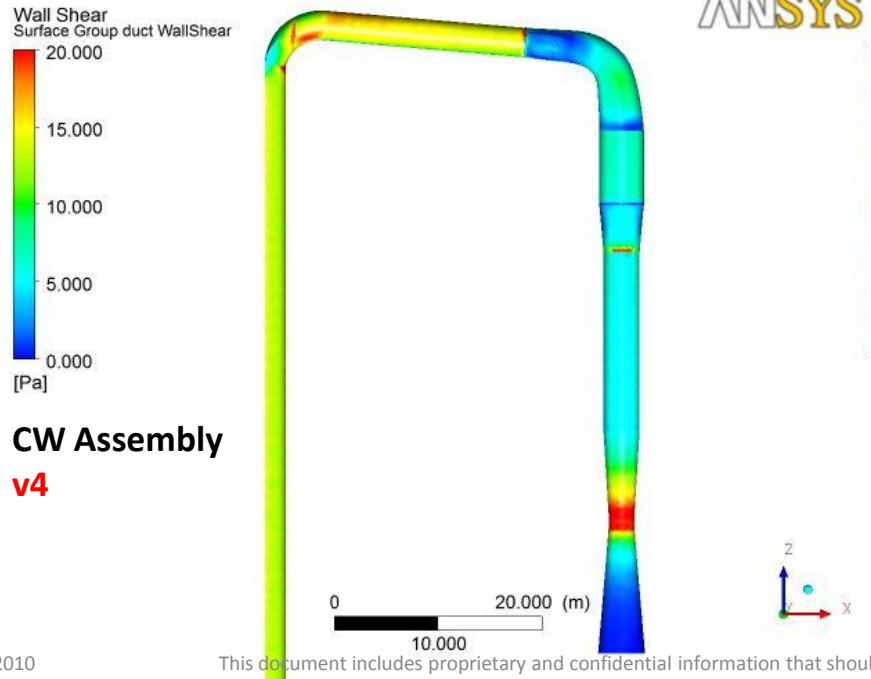
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CW Assembly
v2



CW Assembly
v3



CW Assembly
v4

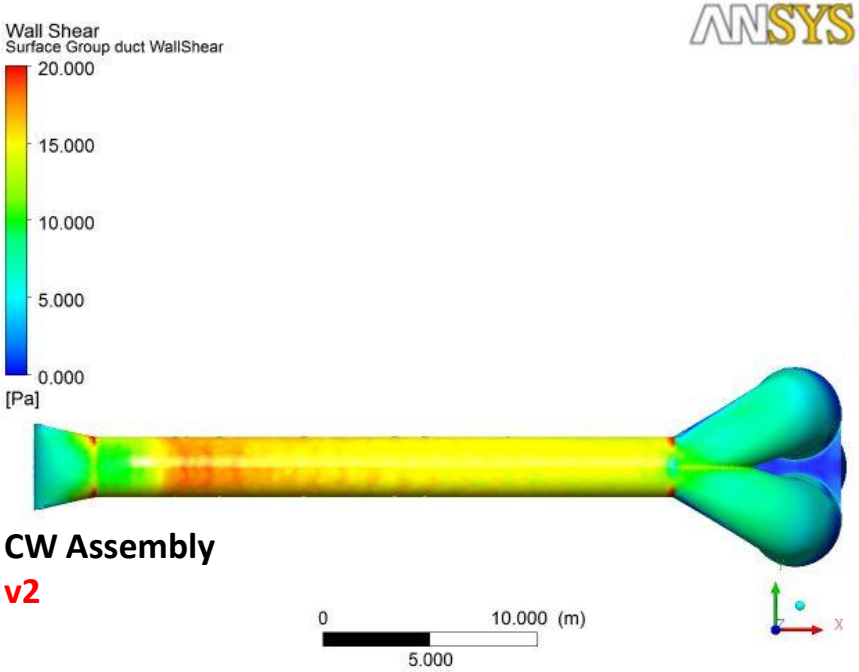
Wall Shear on Pipe Surface

(View normal to XZ plane)

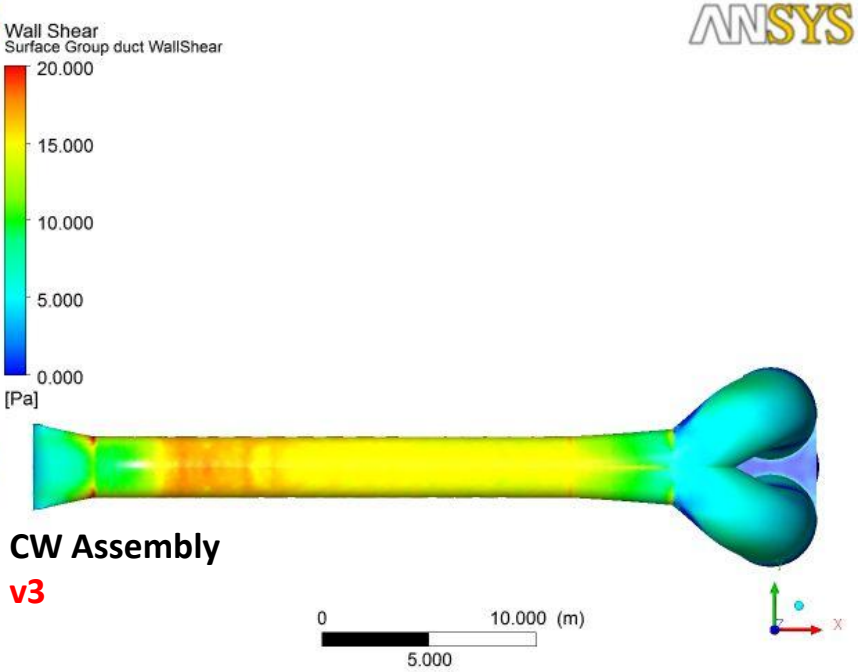
Note:

- Areas of low wall shear can indicate where separation is occurring.

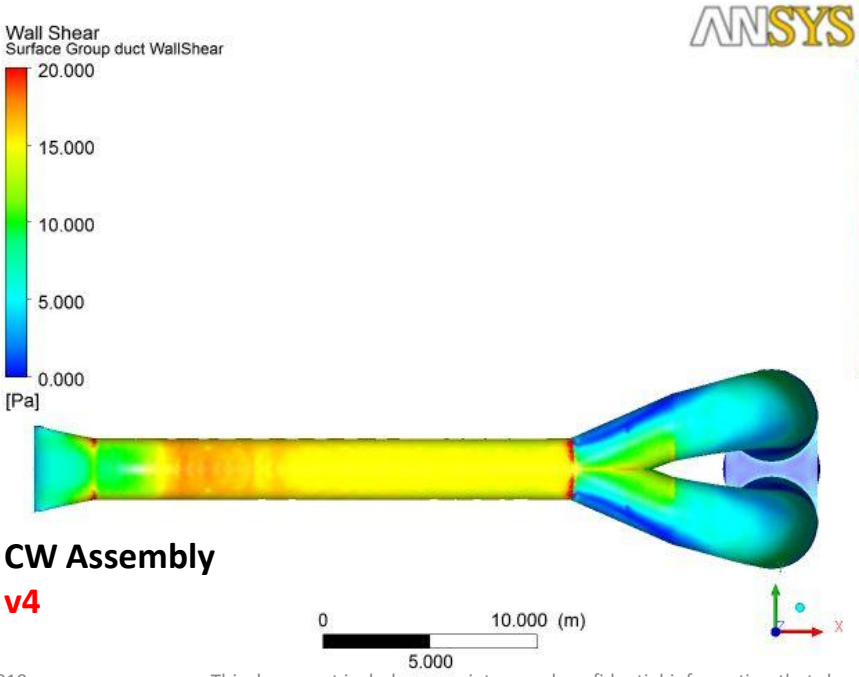
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CW Assembly
v2



CW Assembly
v3

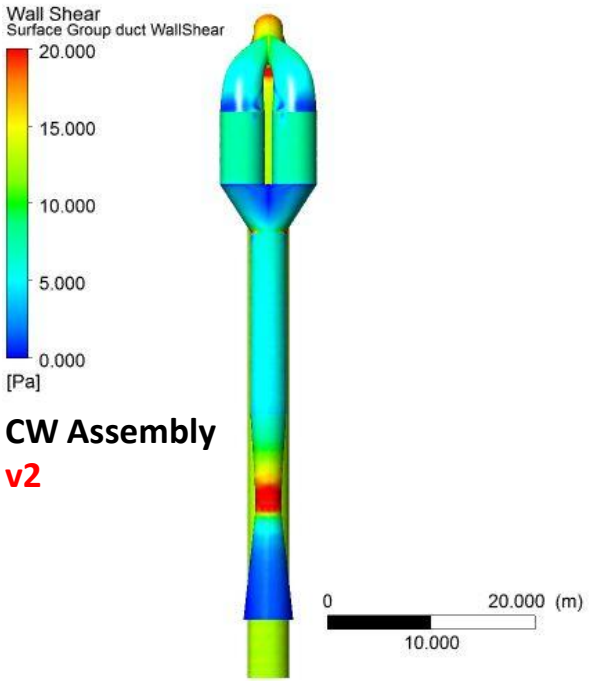


CW Assembly
v4

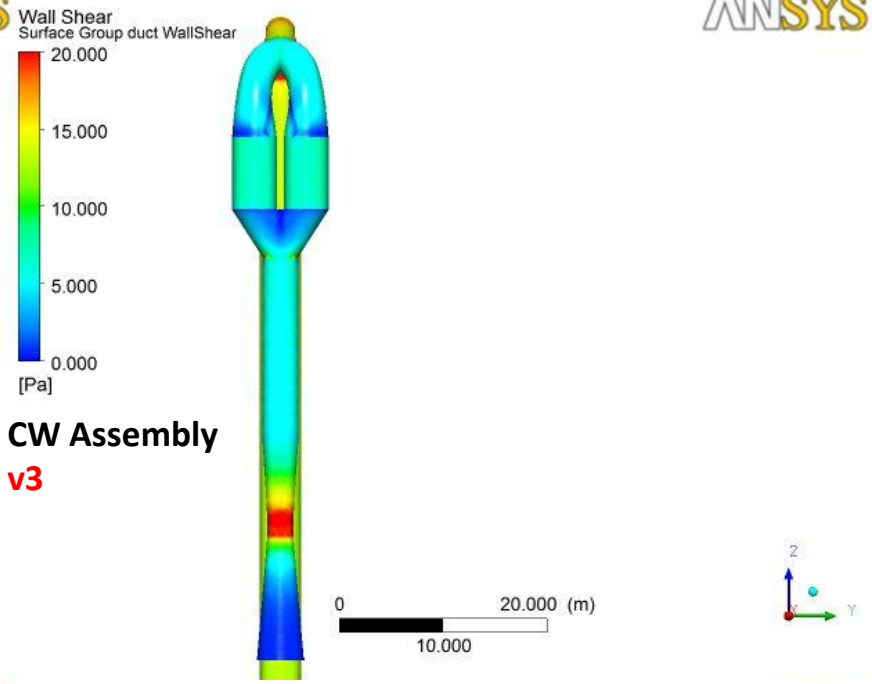
Wall Shear on Pipe Surface

(View normal to XY plane)

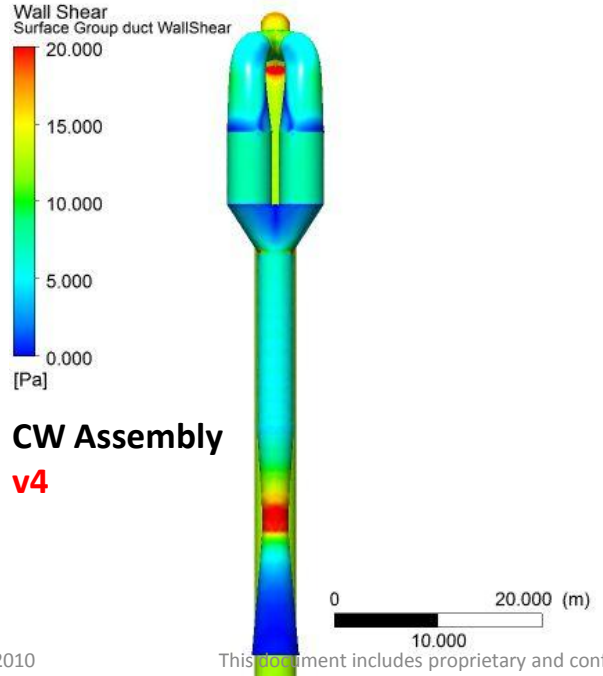
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CW Assembly
v2



CW Assembly
v3

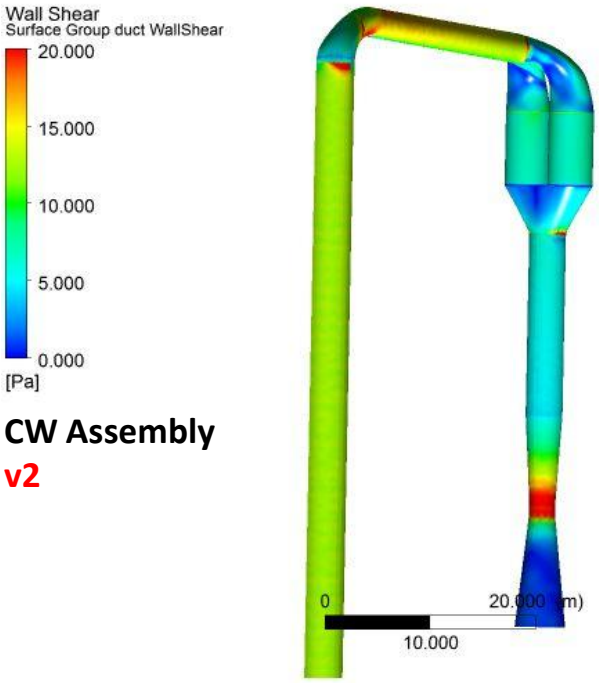


CW Assembly
v4

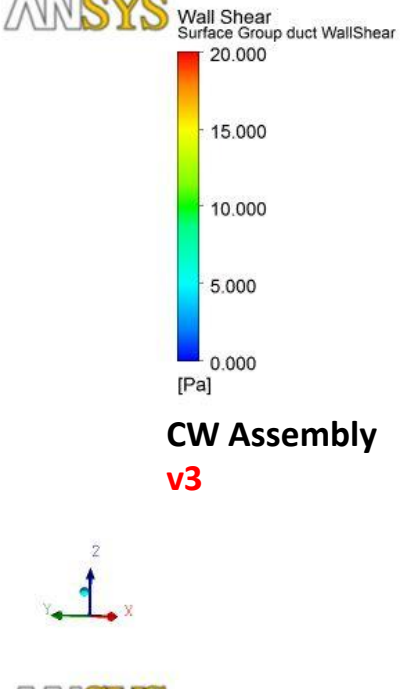
Wall Shear on Pipe Surface

(View normal to YZ plane)

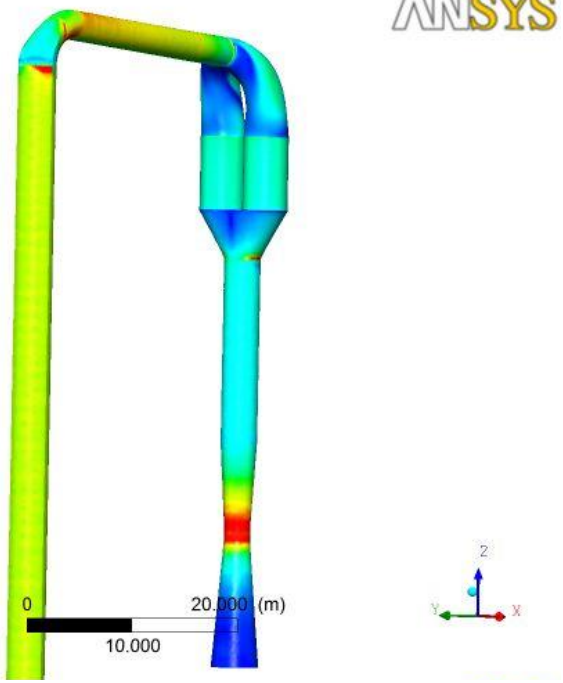
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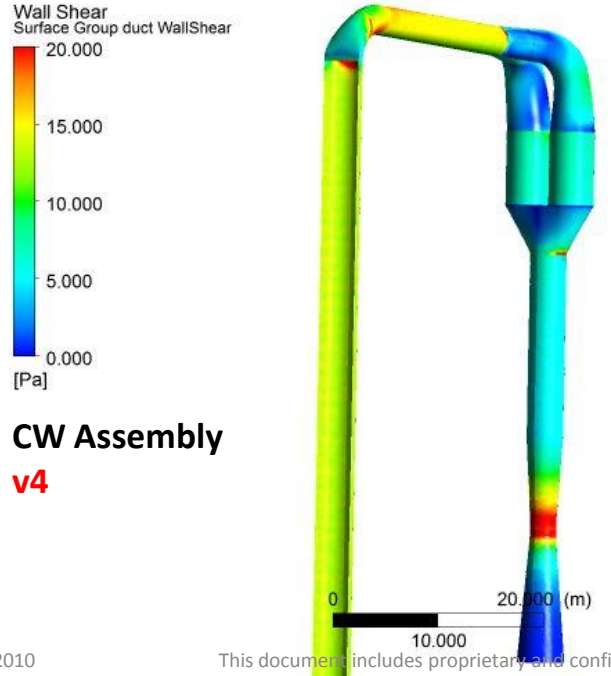


CW Assembly
v2



CW Assembly
v3



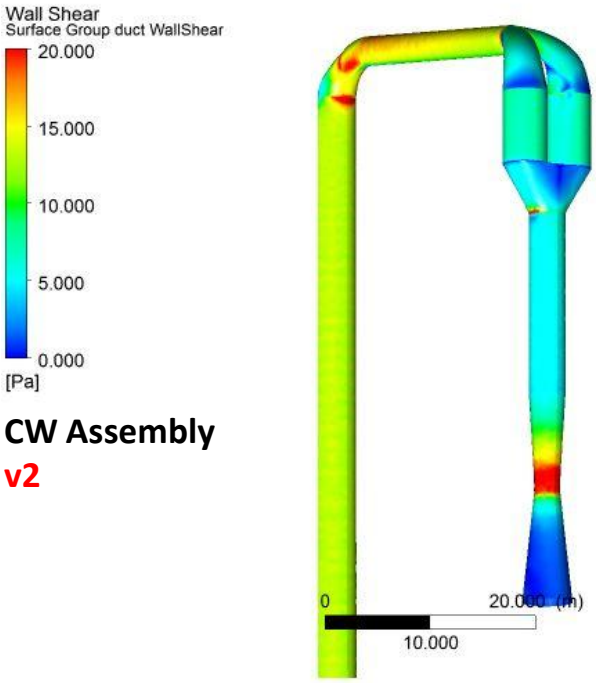


CW Assembly
v4

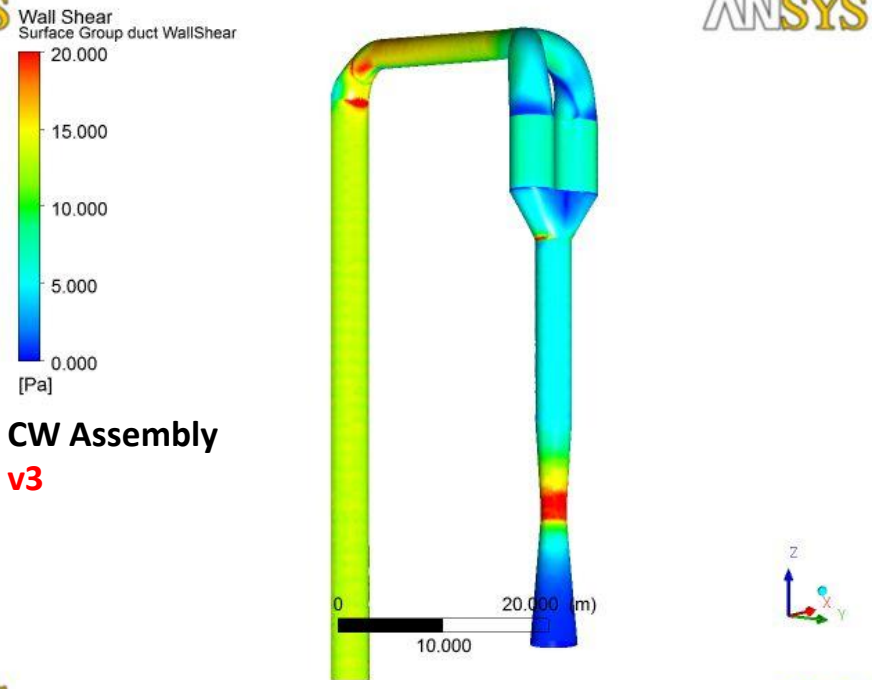
Wall Shear on Pipe Surface

(3D view)

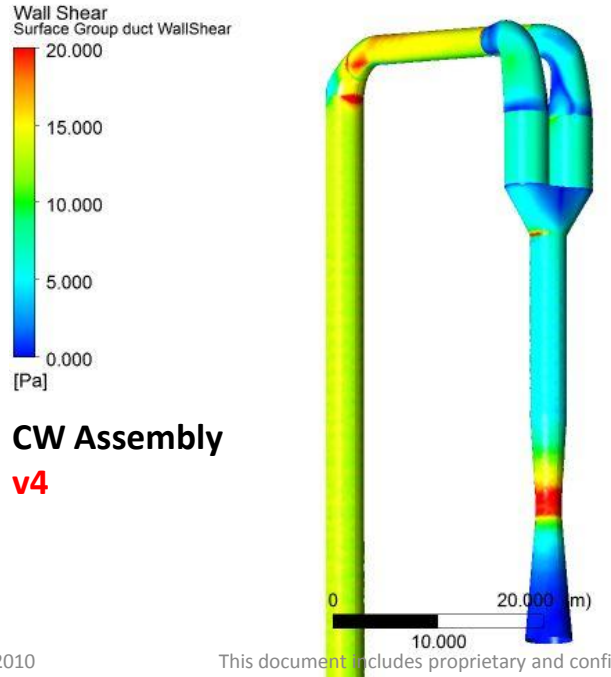
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CW Assembly
v2



CW Assembly
v3



CW Assembly
v4

Wall Shear on Pipe Surface

(3D view)

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Summary

- Flow through bend connecting lead-in duct to cross-over duct:
  - Flow separation still occurs at this bend.
- Flow through cross-connect duct and top piece (CW diffuser manifold, contains split and bend) leading to heat exchanger):
  - The increase in diameter for CW assembly v3 and v4 effectively slowed down the flow velocity through the cross-connect duct and top piece.
  - Vorticity can still be observed in the flow for all versions.
  - The uniformity of flow entering the heat exchanger seems to have improved slightly over CW assembly v2.
  - The pressure drop through the top piece was lowest for CW assembly v3, by ~36% compared to v2 and v4.
- Flow through heat exchanger:
  - Flow is most uniform for CW assembly v4. Flow uniformity in v3 is comparable to v2.
  - The pressure drops across the heat exchanger were slightly lower for CW assembly v3 and v4 compared to v2. This difference is likely due to the lower velocities through the heat exchanger due to the enlarged diffuser.
- Flow at discharge diffuser:
  - Flow at the exit of the CW assembly is most improved in CW assembly v4, and slightly improved in CW assembly v3. Flow is more symmetrical, and recirculation has decreased.
- Summary:
  - The configuration with the lowest losses was CW assembly v3, although flow uniformity through the heat exchanger was comparable to CW assembly v2.
  - The configuration with the most uniform flow across the heat exchanger was CW assembly v4, although losses in the top diffuser piece were comparable to CW assembly v2.
  - The latest version of the diffuser, v2, displayed improved performance over v1.
  - The improved uniformity in flow through the HX observed in CW assembly v4, appeared to carry down through the discharge diffuser. The flow at the exit for this assembly contained the least amount of recirculation and was more uniform over the cross-section.

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OTEC Cold Water Assembly CFD: Status Update

10 June 2010

Prepared by:
M. Parish
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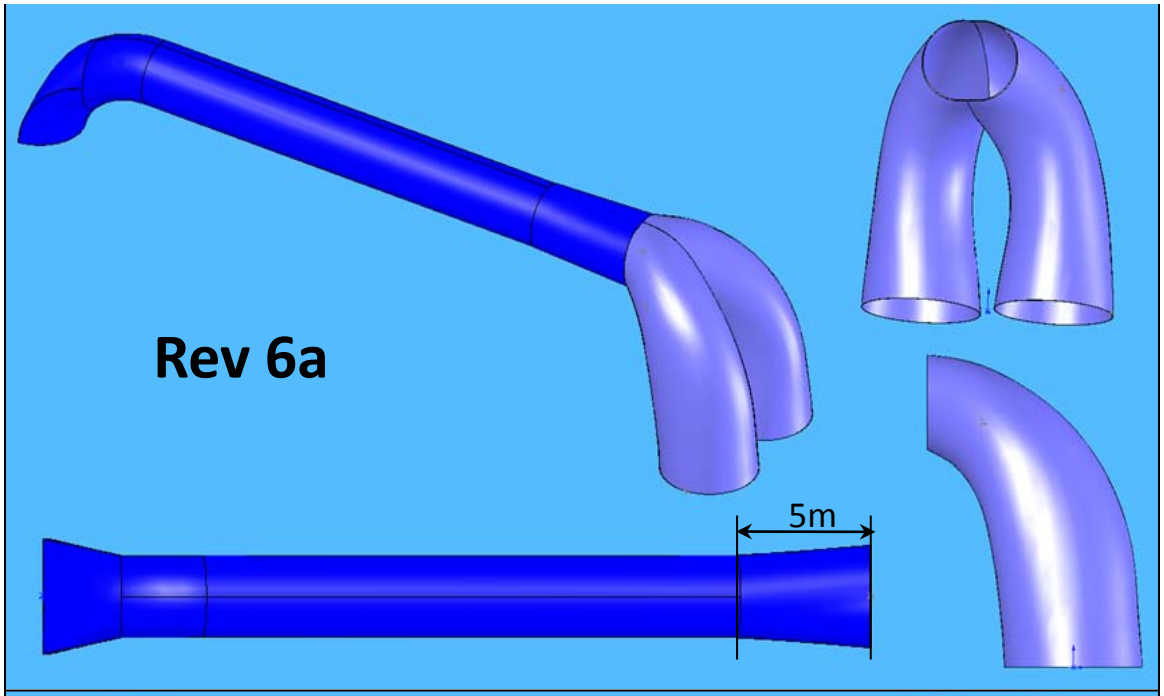
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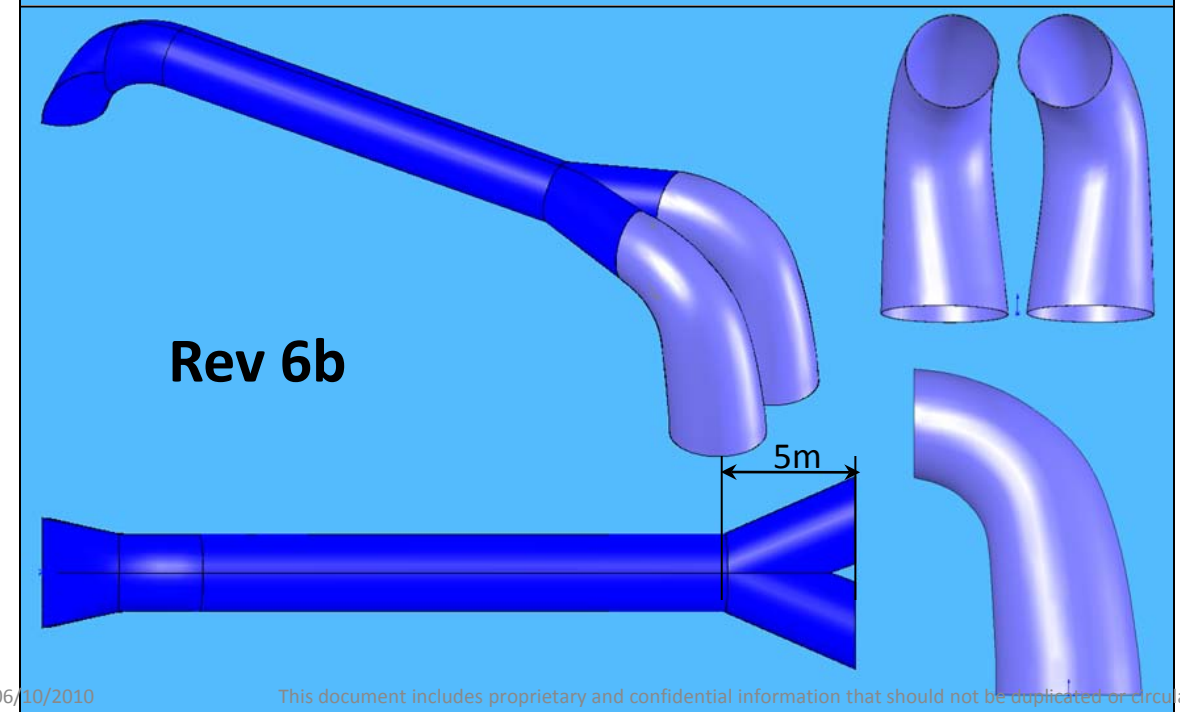
Problem Set-up

- A CFD analysis was performed on two new geometries for the OTEC Cold Water (CW) Assembly.
- The results from a total of three geometries were compared: CW assembly v2, v3, and v4.
  - CW Assembly v3 and v4 contain the latest version of the discharge diffuser (v2).
  - CW assembly v2 contains v5 of the top piece (CW diffuser manifold, top split and bend). These results have been shared in a previous status update.
  - CW assembly v3 contains v6a of the top piece, with the cross-connect duct modified to fit the new top piece.
  - CW assembly v4 contains v6b of the top piece, with the cross-connect duct modified to fit the new top piece.
- Buoyancy (and gravity) were included in the model, and heat transfer was not included in the model.
  - The waterline was set to 18.25 m above the entrance to the cross-connect duct (based on the ducting drawing provided by Makai).
  - No significant changes to the results were noted with the addition of buoyancy to the model.

OTEC CFX Settings		
Geometry	CW assembly v2	Top piece (v5)
	CW assembly v3	Top piece (v6a) Discharge diffuser (v2)
	CW assembly v4	Top piece (v6b) Discharge diffuser (v2)
	Lead-in Duct Length	250.00 m
Flow Properties	Fluid temperature	40 degF
	Fluid density	1027.742 kg/m^3
	Fluid kinematic viscosity	1.59e-6 m^2/s
	Volumetric flow rate	17.8 m^3/s
	Mass flow rate	18,294 kg/s
	Average velocity	Varies
	Reynolds number	Varies (>1e+6)
	Surface roughness FRP pipe	351e-6 m
	Surface roughness steel	60e-6 m
	Friction factor	0.01
CFD Solver	Software	ANSYS CFX v12
	Steady or unsteady	Steady
	Homogeneity	Homogeneous
	Turbulence model	SST, fully turbulent
	Buoyancy	Included
	Heat transfer	None

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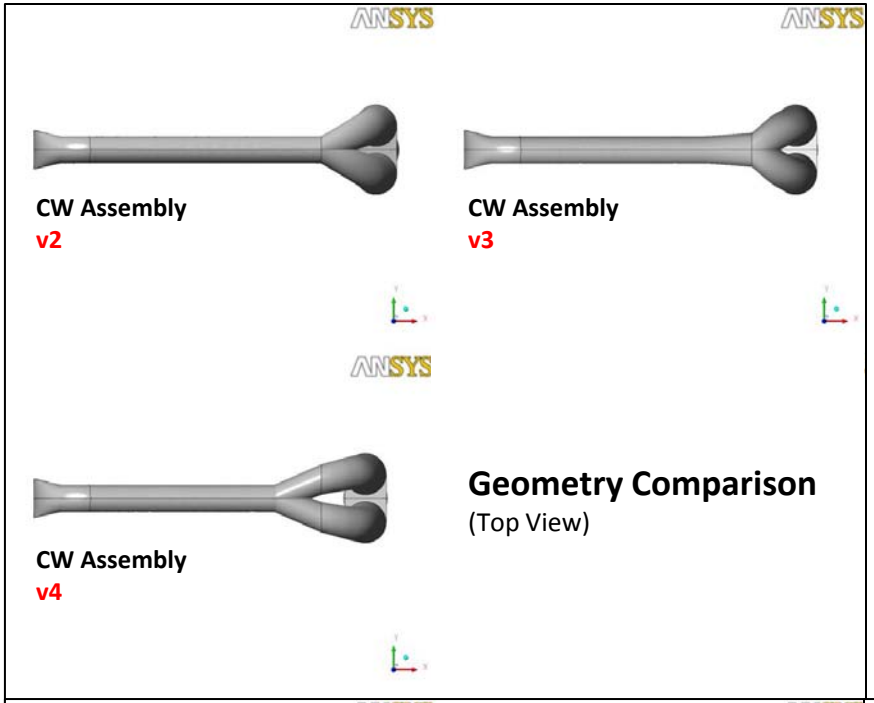




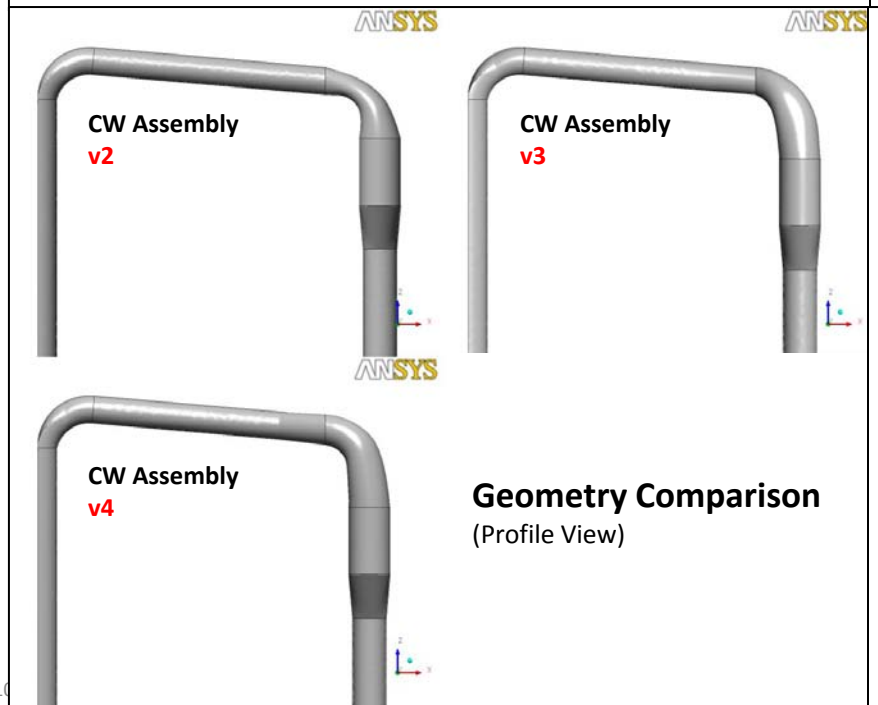
Changes to Cross-connect and Top Piece (CW Diffuser Manifold Split & Bend)

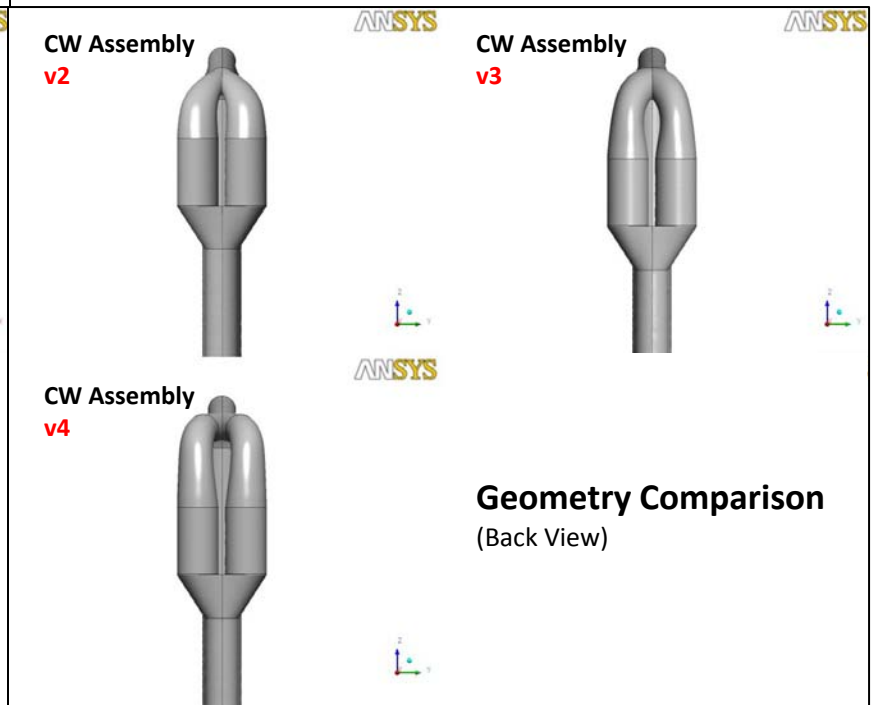
- Changes were made to the top piece (CW diffuser manifold containing split and bend) in order to reduce the vorticity of flow in this area and improve the uniformity of flow entering the heat exchanger.
- The diameter was increased to slow the flow down, and the shape modified to improve the flow.
- The cross-connect duct was modified as well to accommodate the changes in the top pieces.
- Cross-connect and top piece v6a (in CW assembly v3):
  - 11% increase in diameter
  - 25% increase in cross-sectional area
  - Attempt to reduce flow velocity from 2.5 m/s to 2.0 m/s
  - Quasi-elliptical cross-section
  - Improved transition from horizontal to vertical
- Cross-connect and top piece v6b (in CW assembly v4):
  - 11% increase in diameter
  - 25% increase in cross-sectional area
  - Attempt to reduce flow velocity from 2.5 m/s to 2.0 m/s
  - Split earlier in cross-over pipe
  - Circular cross-sections
  - Improved transition from horizontal to vertical

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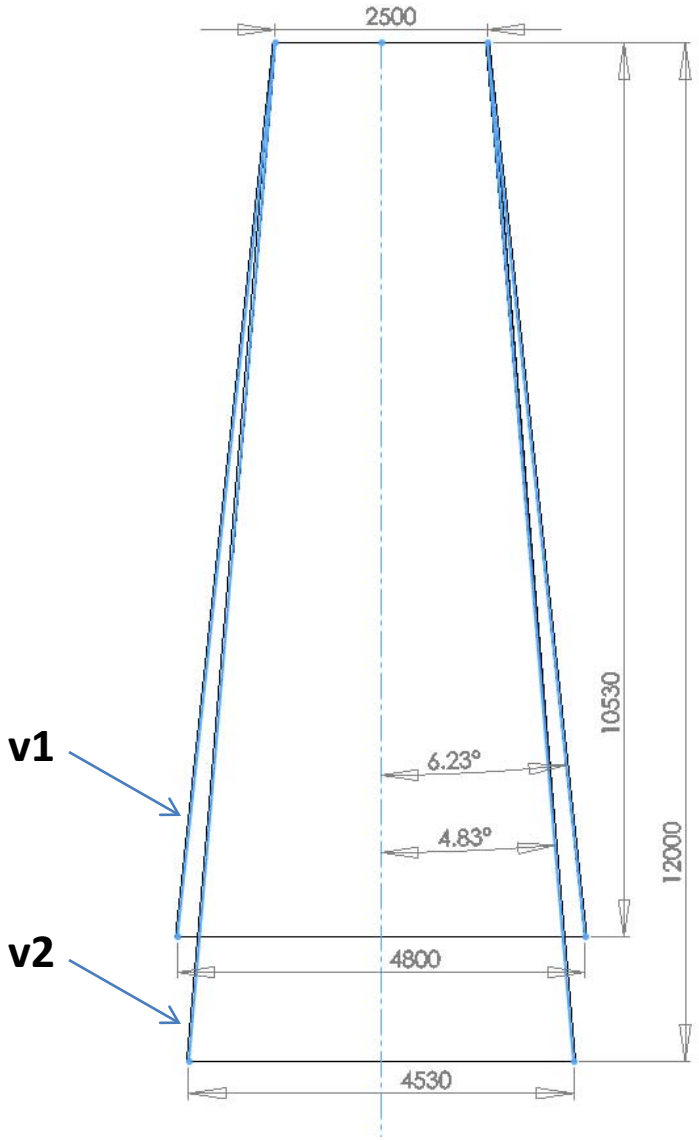
Geometry Comparison: Changes to Cross-connect and Top Piece (CW Diffuser Manifold Split & Bend)





Changes to Discharge Diffuser

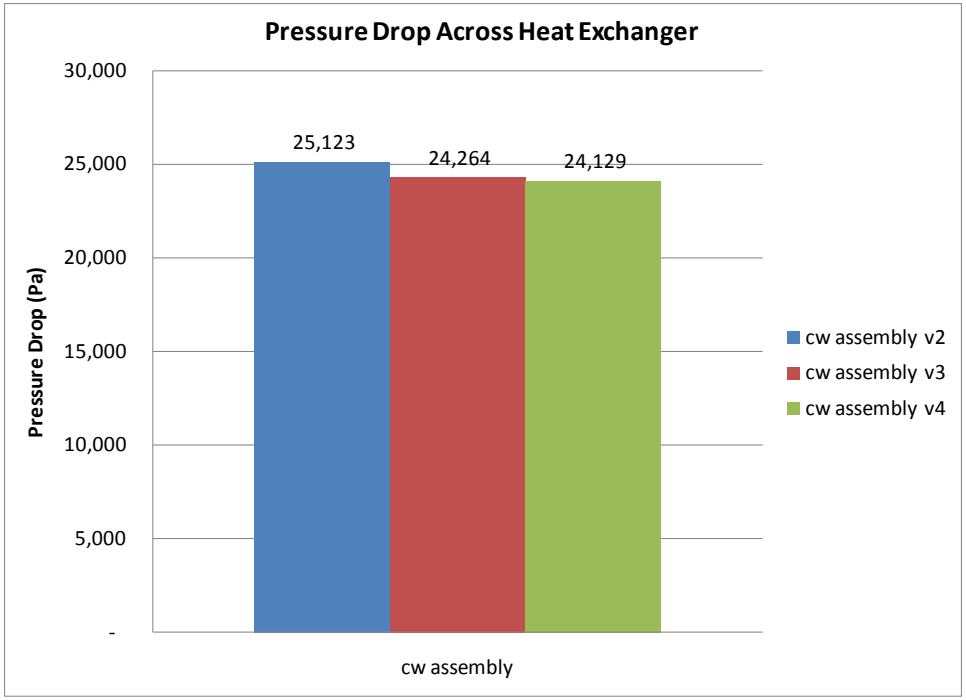
- The discharge diffuser at the bottom of the CW assembly was modified to reduce the recirculation of flow observed at the exit of the CW assembly.
- The diffuser angle was decreased, and the length increased from v1 to v2.



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Pressure Drop Across HX

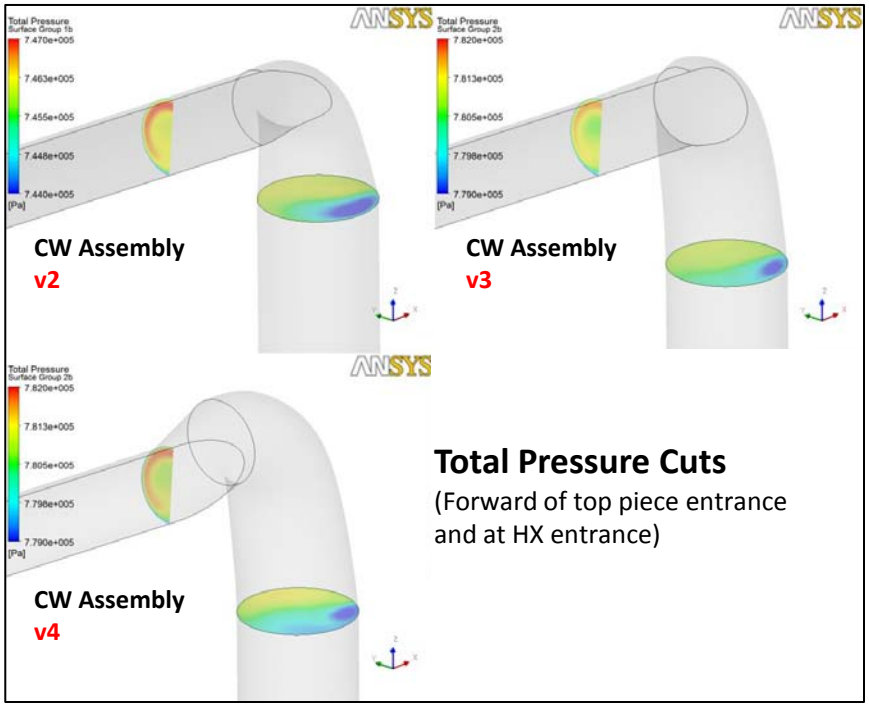
- The Cold Water (CW) Heat Exchanger (HX) was modeled as a porous domain.
  - The porosity was set to the design value of 40%.
  - The resistance parallel to the flow direction was set to 8500 kg/m^4, where the aim was to get the pressure drop across the HX close to the theoretical prediction of 24.5 kPa.
  - The resistance perpendicular to the flow direction was set to 100x the resistance parallel to the flow direction to bring the streamlines through the HX closer to vertical.
- The parameters for the porous domain were kept consistent across all models to be able to compare the different designs.
- A mass flow average was taken at the entrance and exit of the HX to calculate the pressure drop.
- Compared to the pressure drop across the HX for v1 of the CW assembly, the pressure drop was 3.4% lower for v2, and 4.0% lower for v3.
- (For further comparison and study, the parameters for the HX could also be varied so that the pressure drop was consistent for all three versions.)

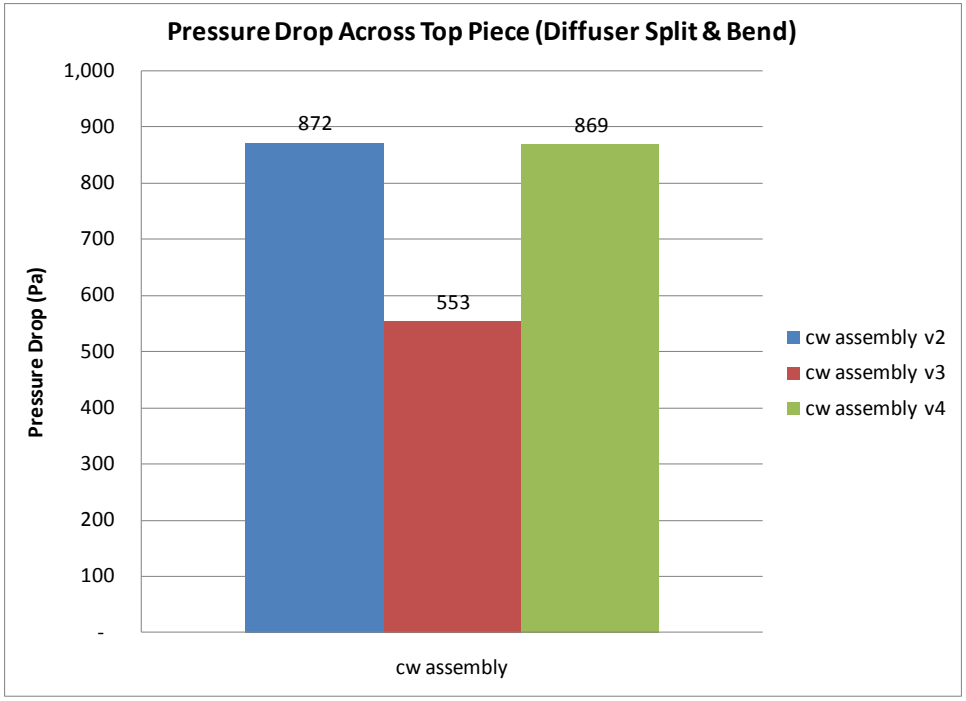


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Pressure Drop Across Top Piece (Diffuser Split & Bend)

- The pressure drop was evaluated across the top piece containing the diffuser split and bend.
  - The first plane where pressure was measured (averaged by mass flow across the plane) was taken slightly forward of the entrance to the top piece. The second plane where pressure was measured was taken at the entrance to the heat exchanger. The locations of measurement were consistent for all three assemblies
- The pressure drop was lowest for CW assembly v3.



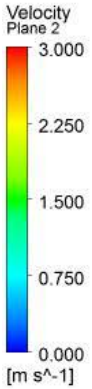


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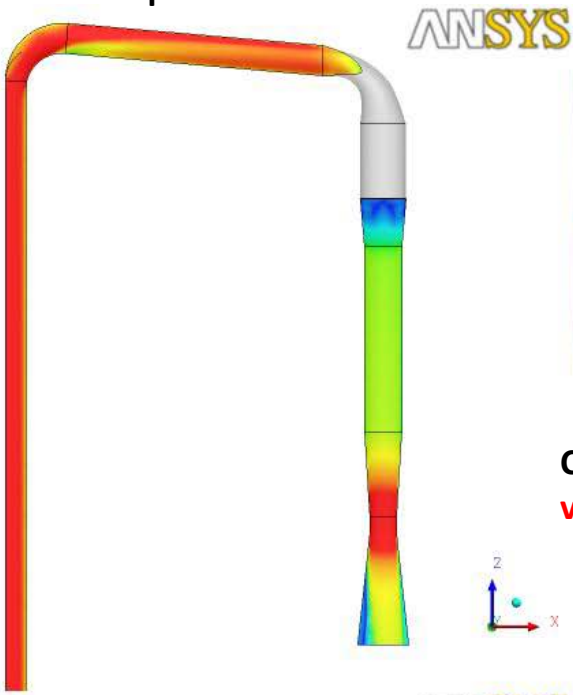
Notes on Variable Definitions

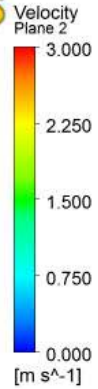
- The variable "Total Pressure" as defined in the CFX help files:
  - "The total pressure, P_{total}, is defined as the pressure that would exist at a point if the fluid was brought instantaneously to rest such that the dynamic energy of the flow converted to pressure without losses."
  - "For incompressible flows, such as those of liquids and low speed gas flows, the total pressure is given by Bernoulli's equation: $P_{total} = P_{static} + ½*\rho*(\mathbf{U}\cdot\mathbf{U})$"
- The Total Pressure was converted to Total Energy per unit mass of fluid (with units of Joules/kg) using the equation: $E_{total} = P_{total} / \rho$
- Note that the Total Pressure can also be converted to total head (in meters) using: $h_{total} = P_{total} / \rho g$

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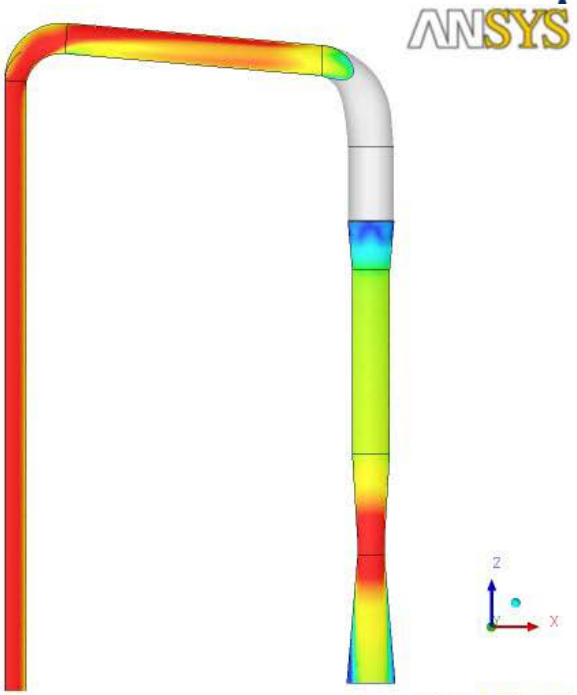


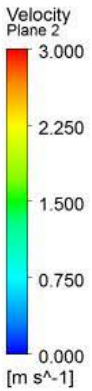
CW Assembly
v2



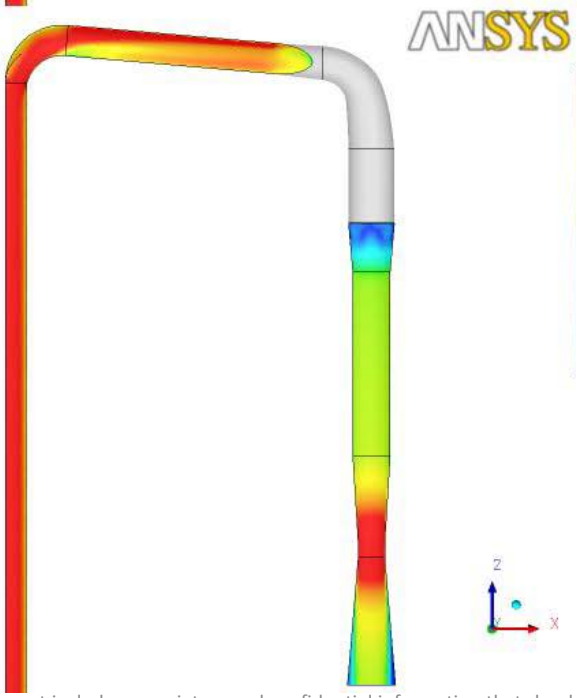


CW Assembly
v3





CW Assembly
v4



Velocity Cuts at Y=0m

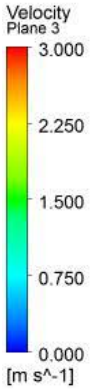
(Centerline of Assembly in XZ plane)

Observations:

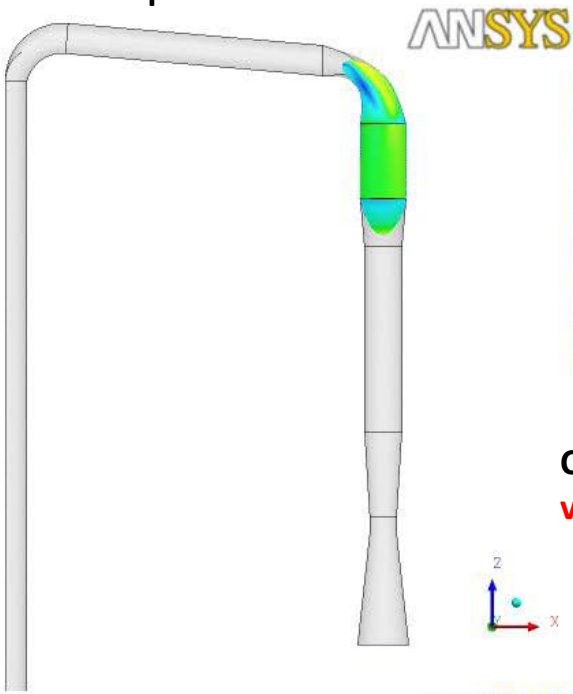
- Increase in diameter effectively slowed down flow velocity through cross-connect duct and top piece in CW assembly v3 and v4.
- Flow at discharge of CW assembly improved for CW assembly v3 and v4. There is less recirculation, and flow profile is more uniform (see also Slide 19).

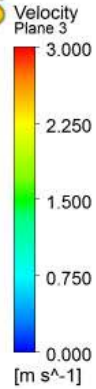
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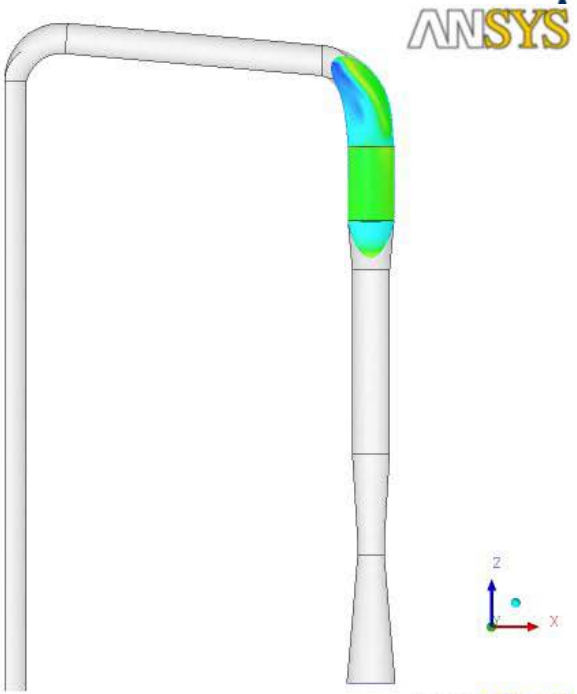


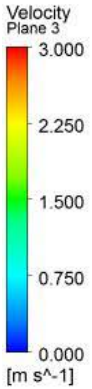
CW Assembly
v2



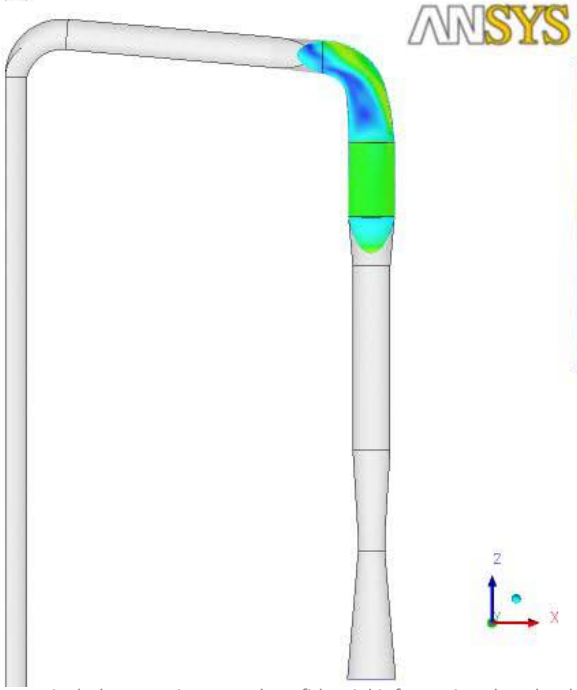


CW Assembly
v3





CW Assembly
v4



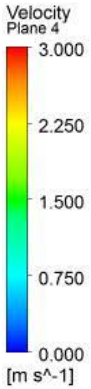
Velocity Cuts at Y=2.5m

(Centerline of HX in XZ plane)

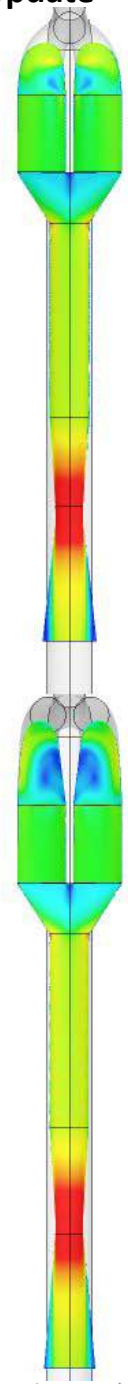
Observations:

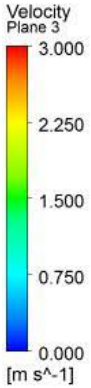
- Flow in the top piece slows down a greater amount in v3 compared to v2, and more so in v4 of the CW assembly.

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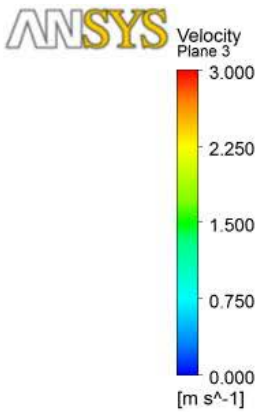


CW Assembly
v2

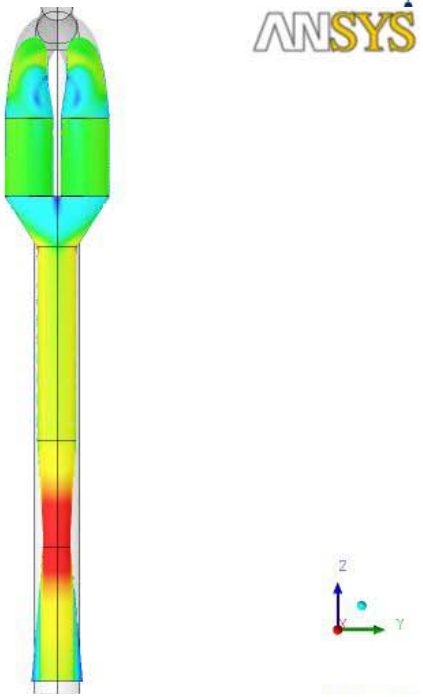




CW Assembly
v4



CW Assembly
v3

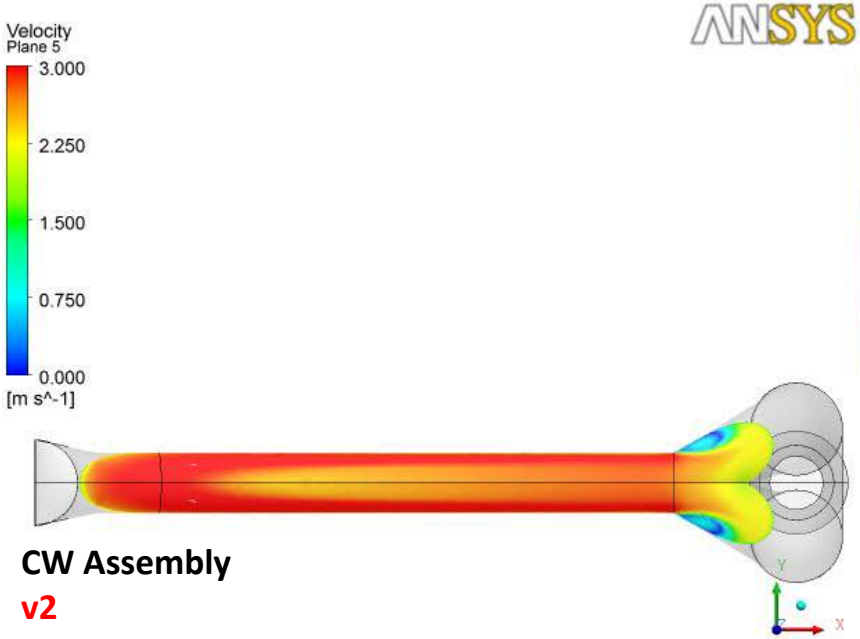




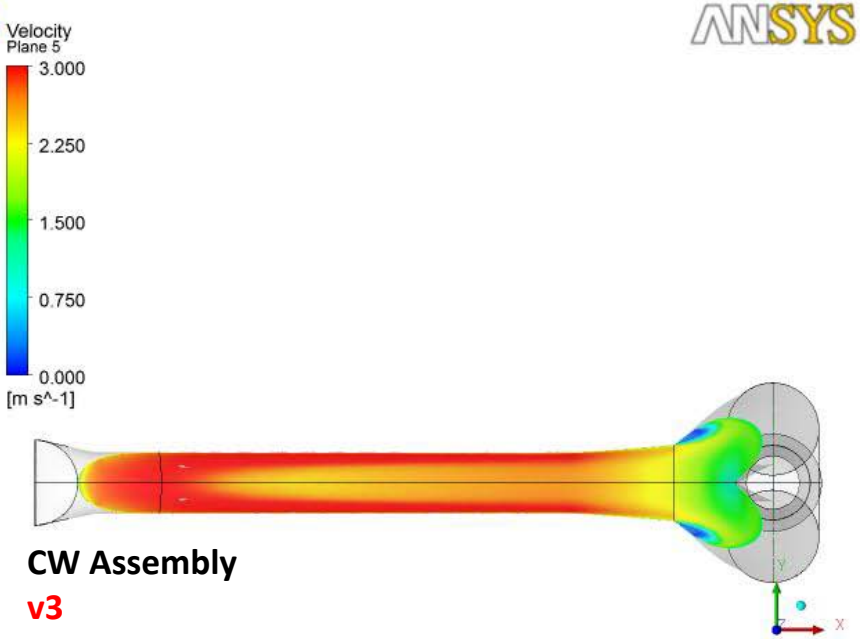
Velocity Cuts at X=35.5m (v2), X=34.4m (v3 & v4)

(Centerline of HX in YZ plane)

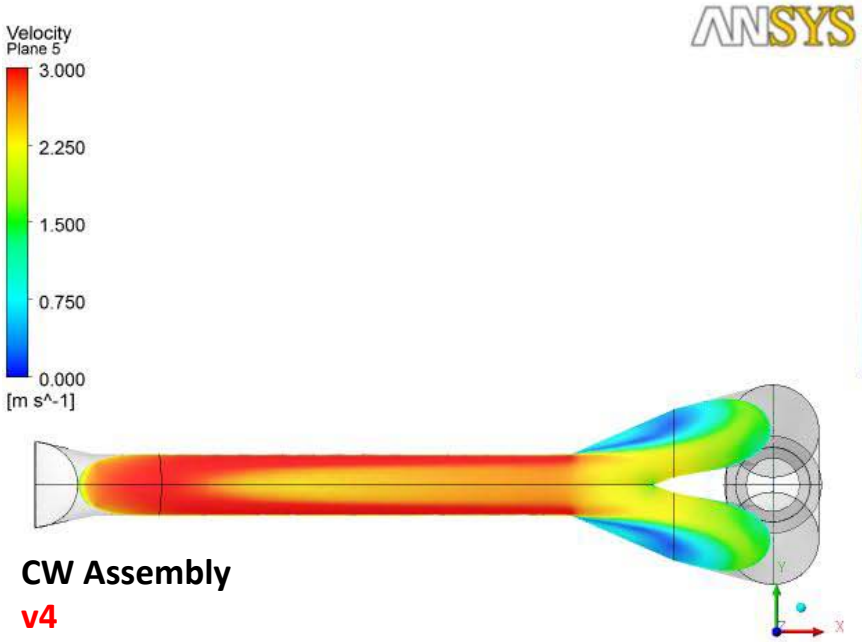
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CW Assembly
v2



CW Assembly
v3



CW Assembly
v4

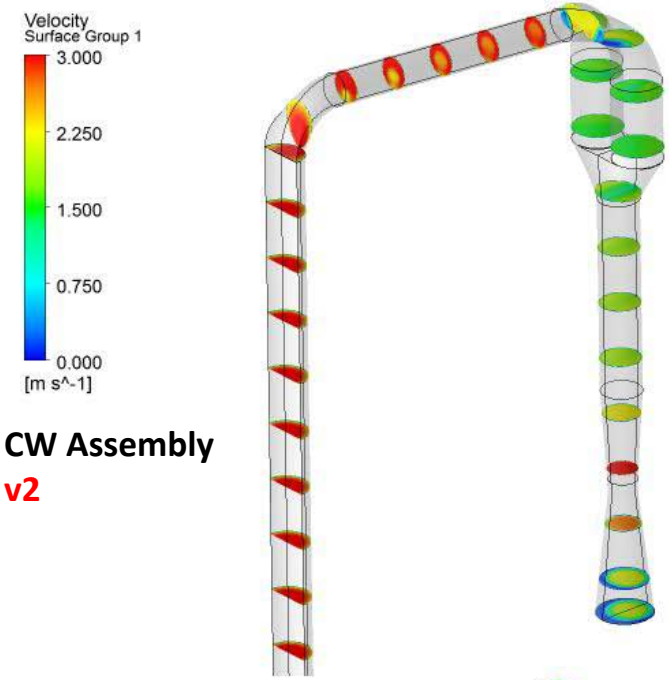
Velocity Cuts in Plane of Cross-Connect Duct, Viewed Normal to XY Plane

(Centerline of cross-connect duct in plane parallel to direction of flow in cross-connect duct)

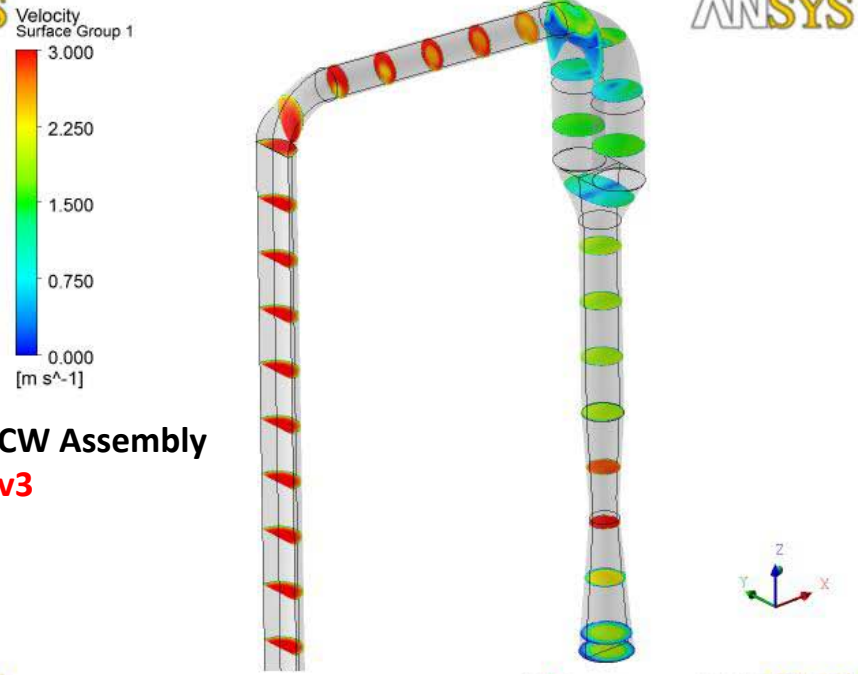
Observations:

- Greater amount of flow separation leading into the top piece can be observed in CW assembly v4, and less in v3.

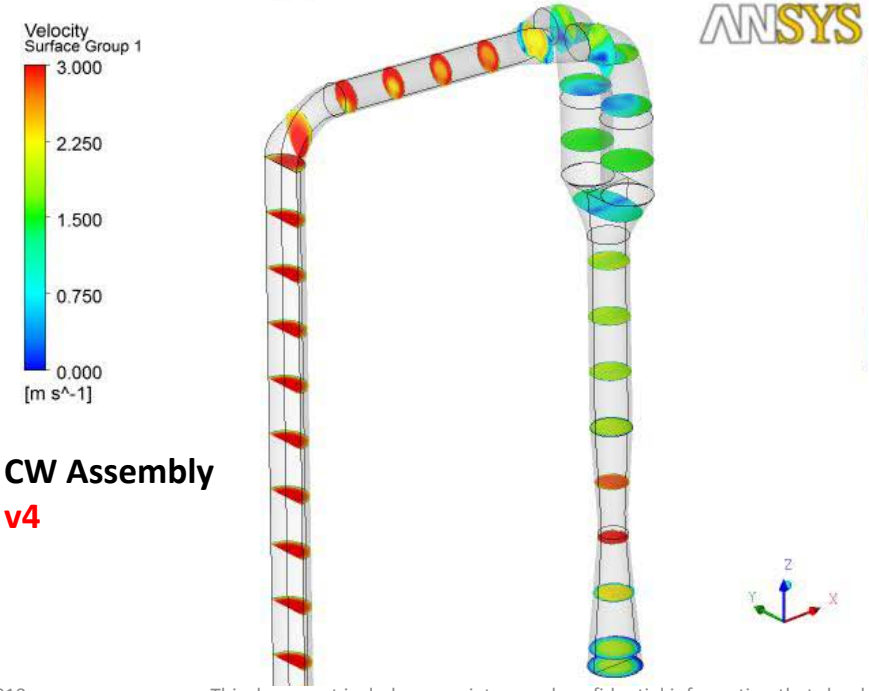
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CW Assembly
v2



CW Assembly
v3

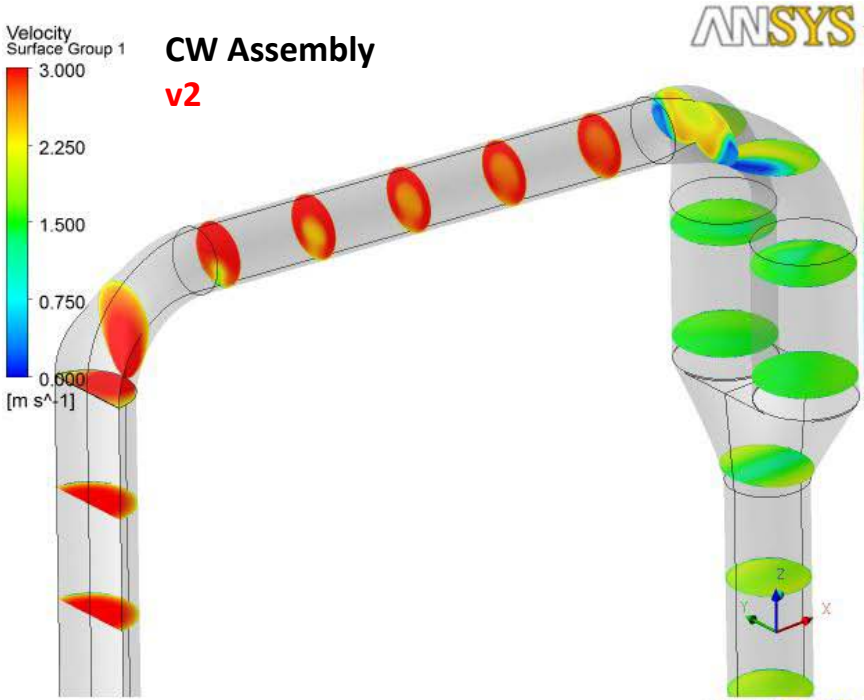


CW Assembly
v4

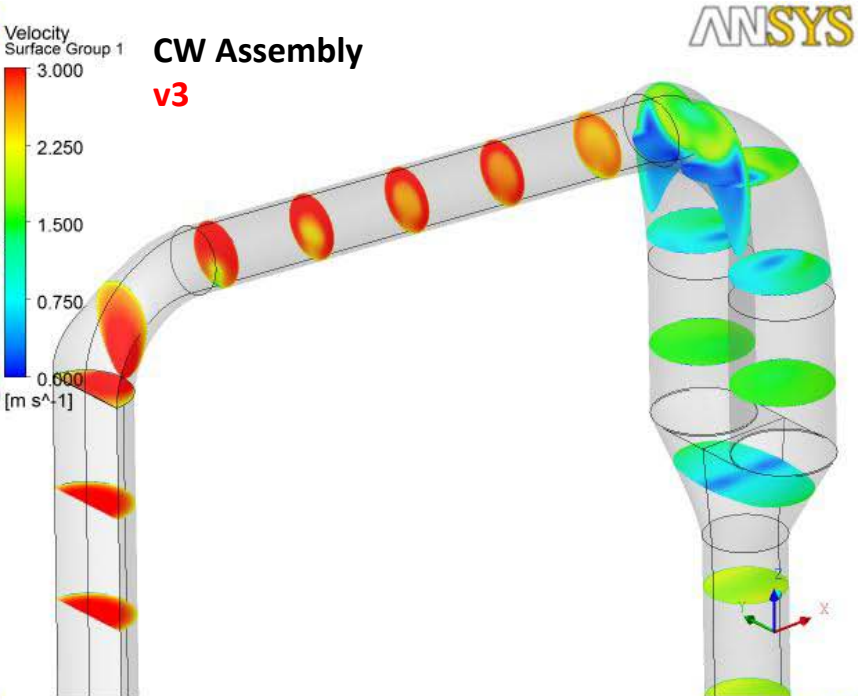
Velocity Cuts

(In X and Z every ~5 m)

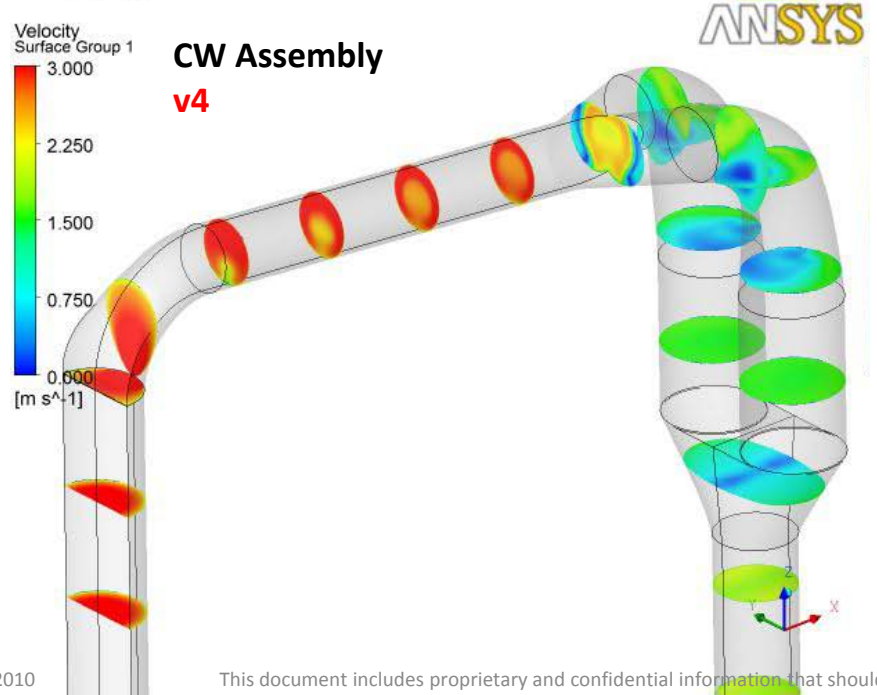
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CW Assembly
v2



CW Assembly
v3

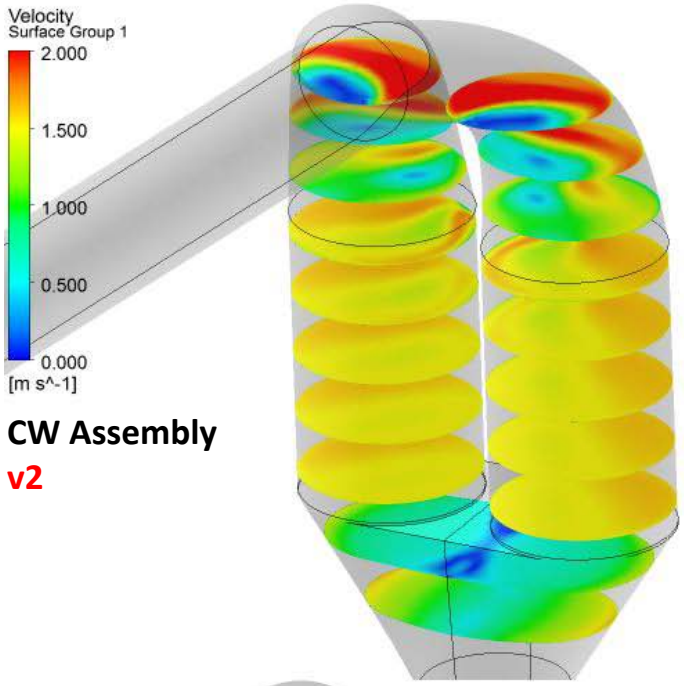


CW Assembly
v4

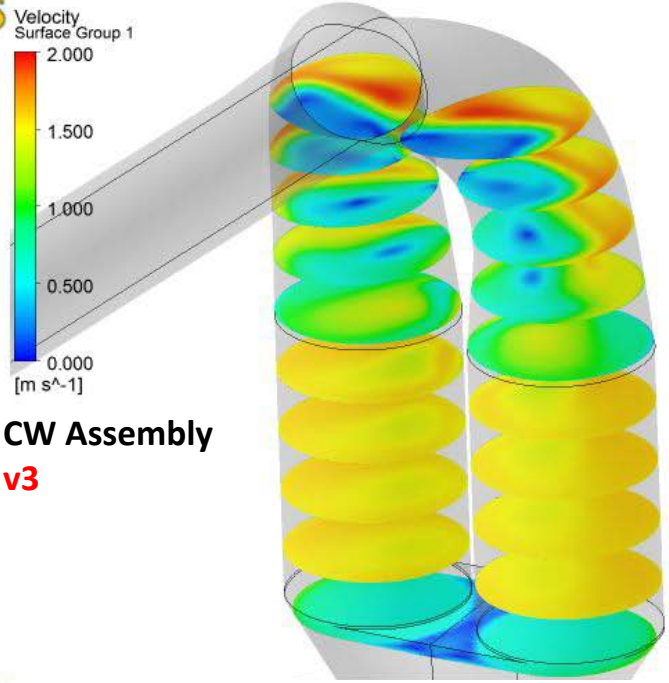
Velocity Cuts

(In X and Z every ~5 m)

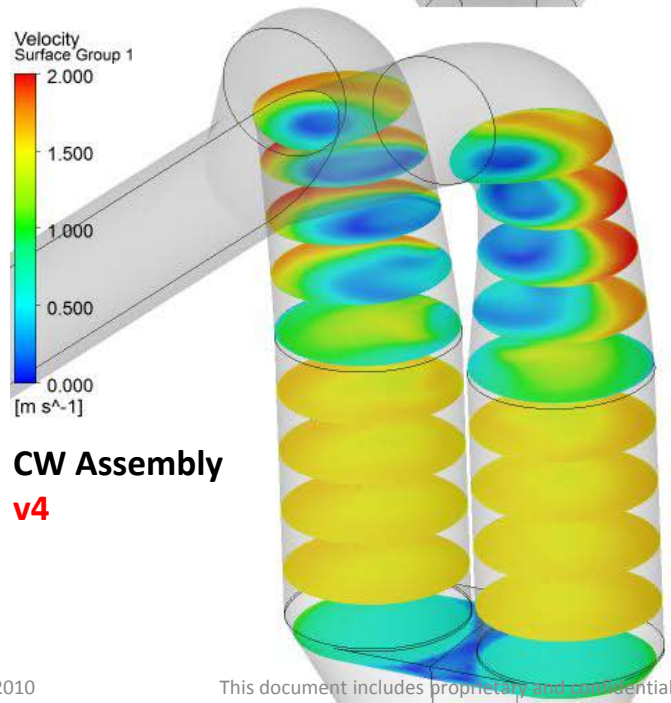
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CW Assembly
v2



CW Assembly
v3



CW Assembly
v4

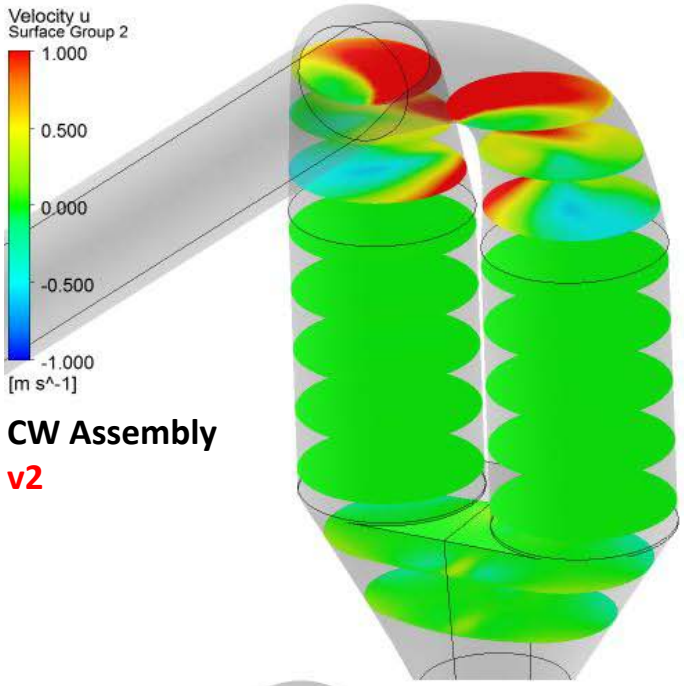
HX Velocity Cuts

(In Z every ~1.5 m)

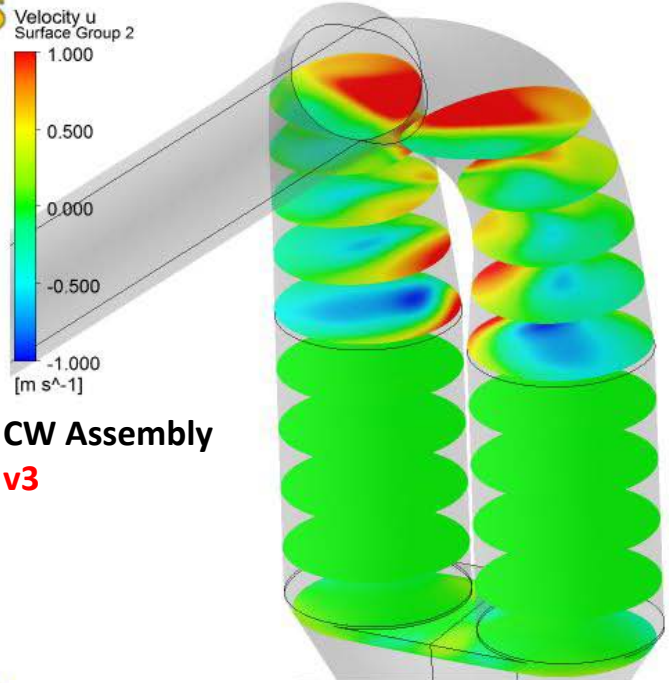
Observations:

- Although flow is still not uniform through the heat exchanger, uniformity seems to have improved slightly in CW assembly v4 due to slow-down of the flow.

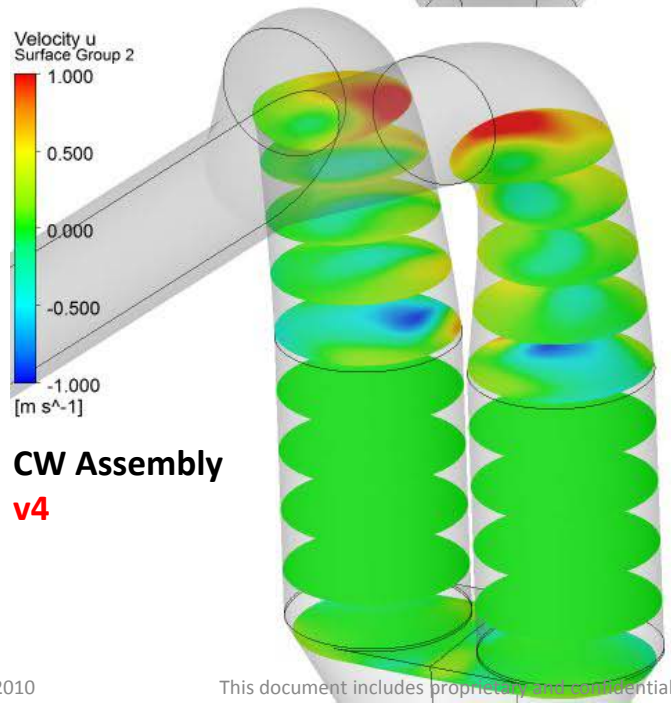
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CW Assembly
v2



CW Assembly
v3



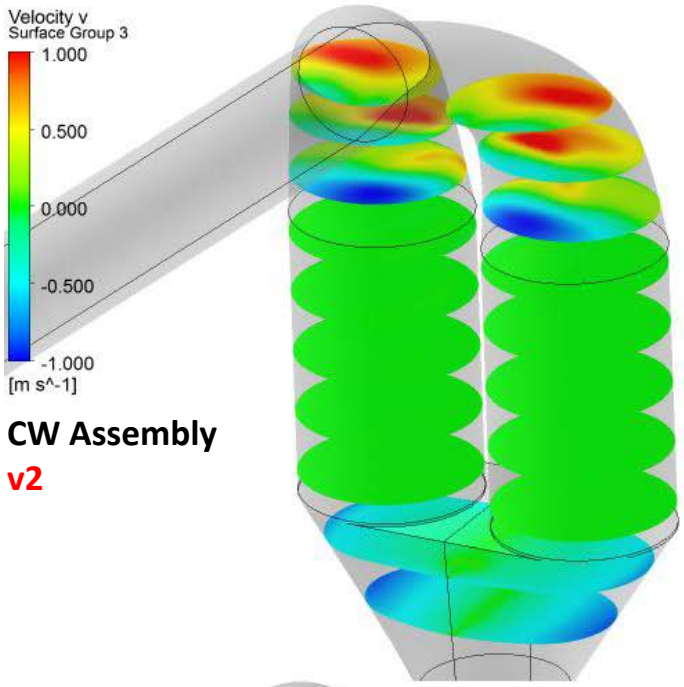
CW Assembly
v4

HX Velocity Cuts in U

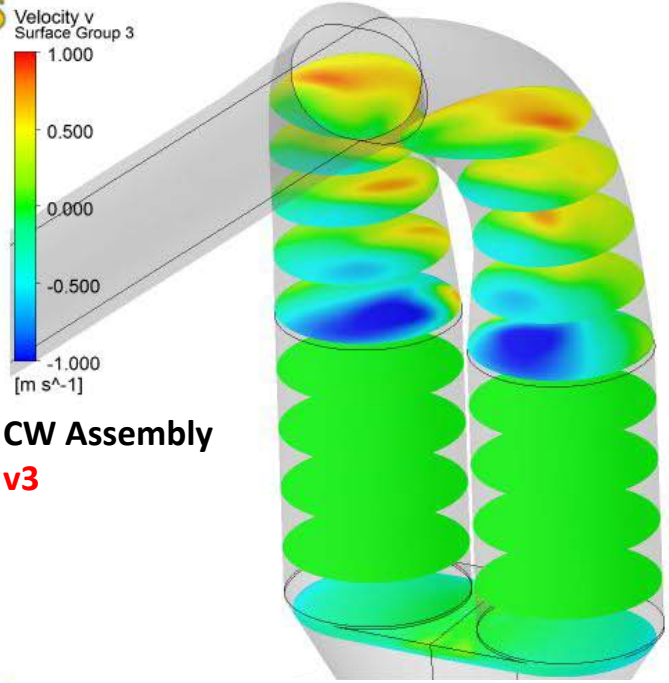
(In Z every ~1.5 m)

Note: direction of flow into the paper is positive, out of the paper is negative

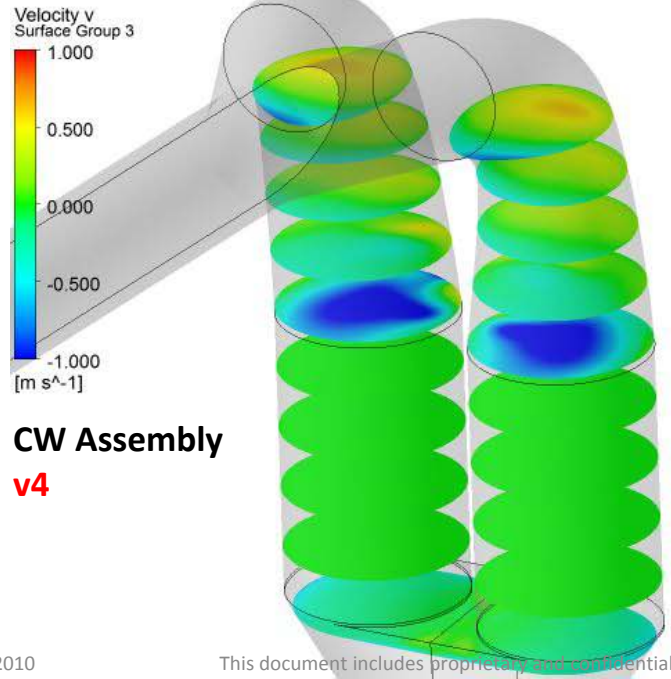
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CW Assembly
v2



CW Assembly
v3



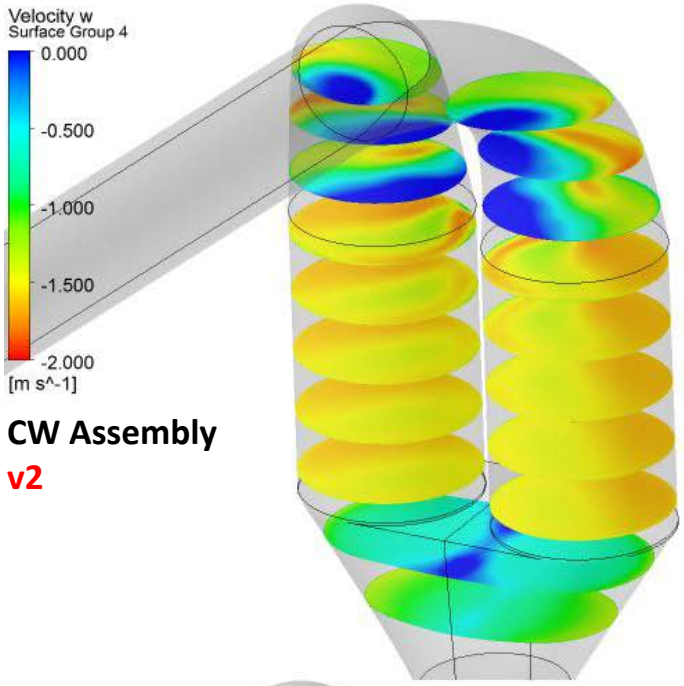
CW Assembly
v4

HX Velocity Cuts in V

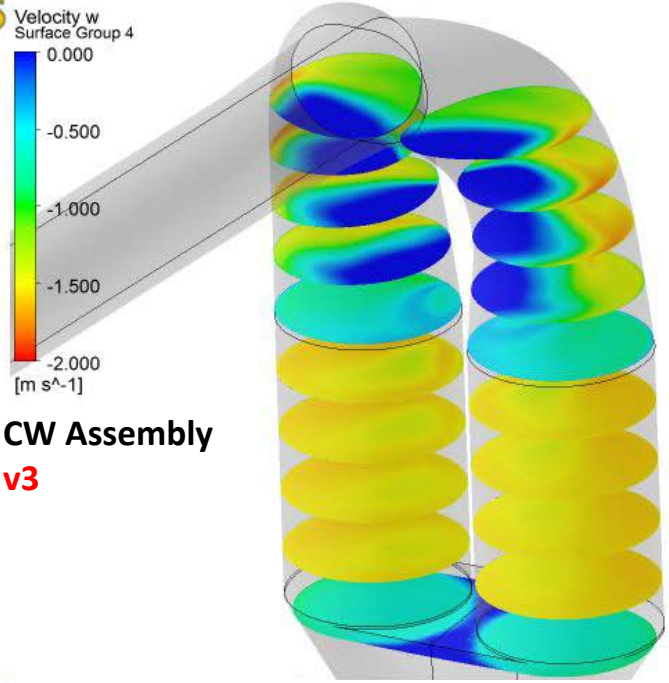
(In Z every ~1.5 m)

Note: only half of the CW assembly was meshed (the half on the positive-Y, or left side looking at this image), and a symmetry plane defined in the solver to model the other half. The screenshots were created by selecting a mirror image to be shown in the post-processor. Thus, the mirrored (right) half for this image should be opposite in color, ranging from -1 m/s as red to +1 m/s as blue.

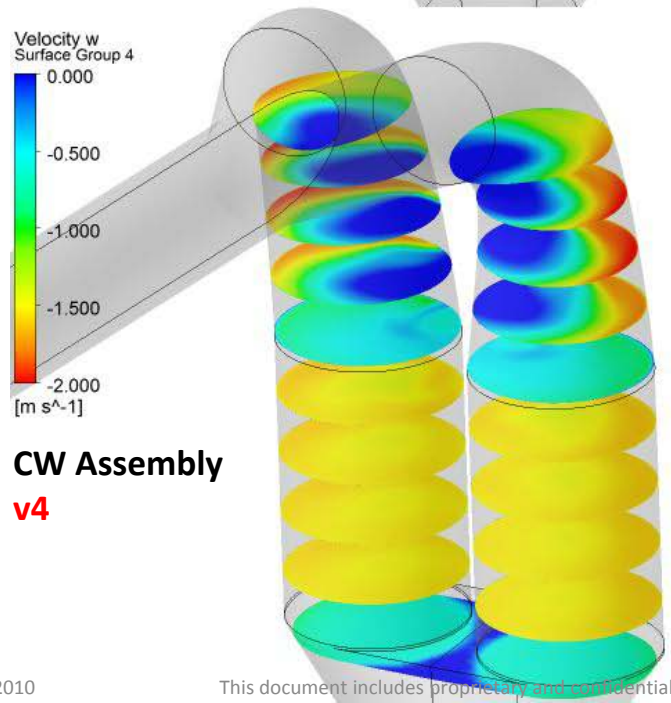
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CW Assembly
v2



CW Assembly
v3



CW Assembly
v4

HX Velocity Cuts in W

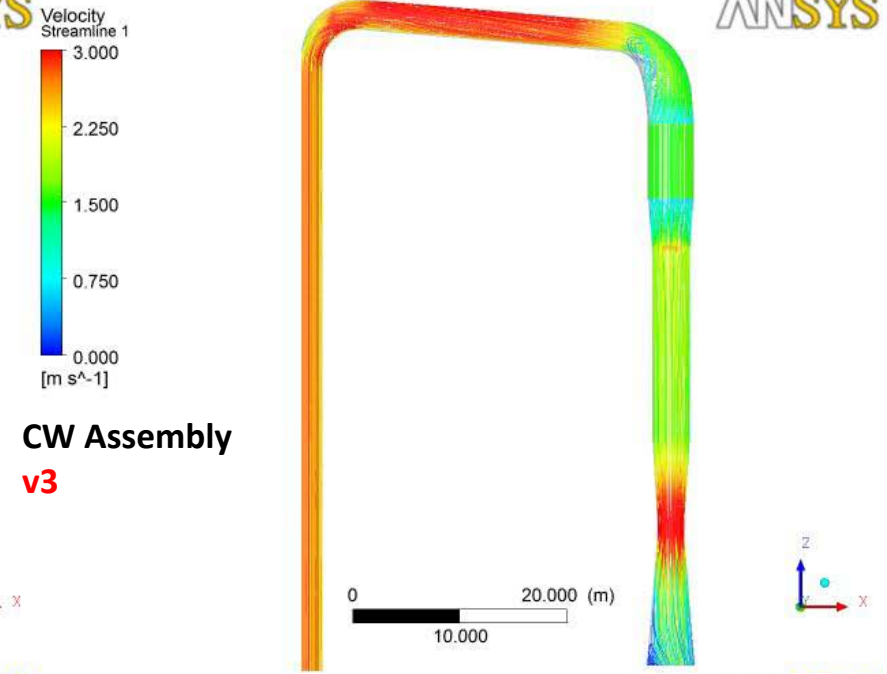
(In Z every 1.5 m)

Note: up is positive, down is negative

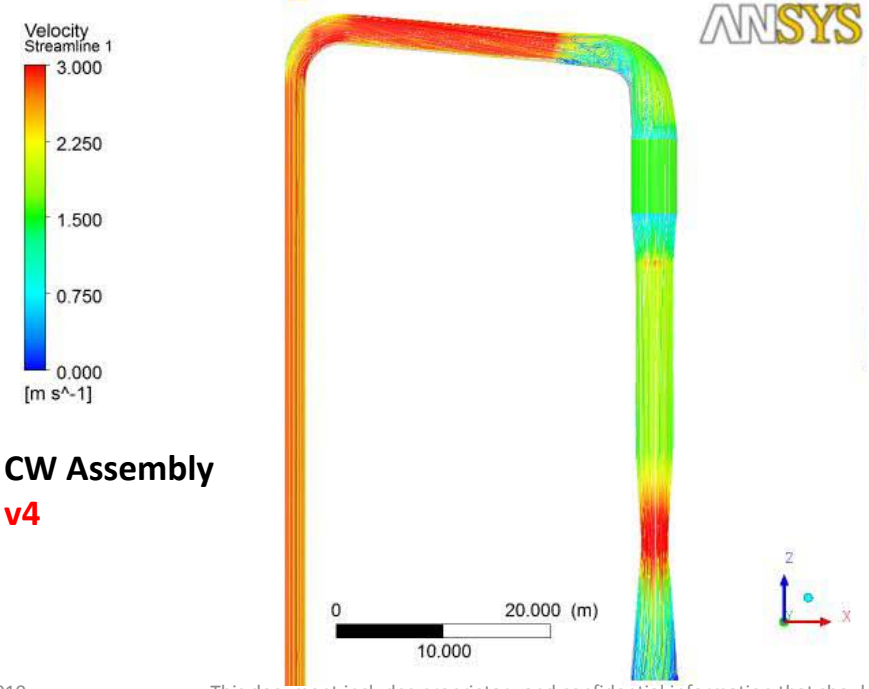
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CW Assembly
v2



CW Assembly
v3



CW Assembly
v4

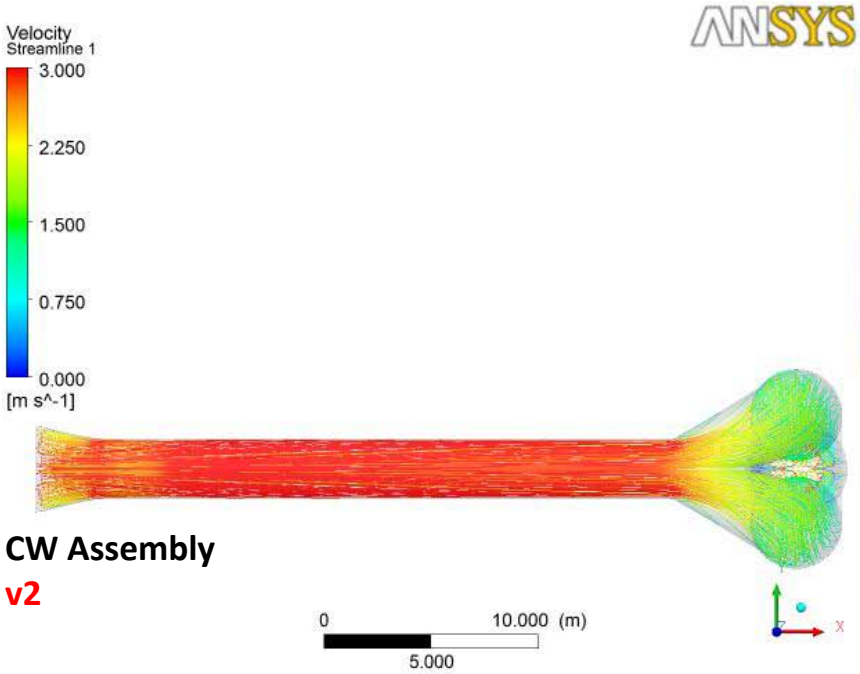
Velocity Streamlines

(View normal to XZ plane)

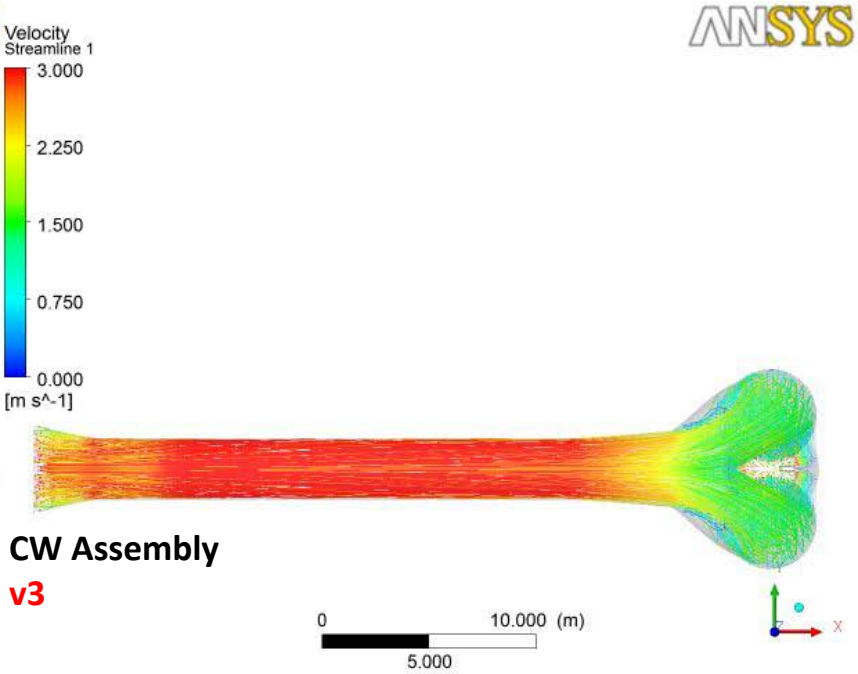
Observations:

- Flow at CW assembly discharge improved slightly for CW assembly v3, and greatly for CW assembly v4. There is less recirculation, and flow profile is more uniform (see also slide 9).

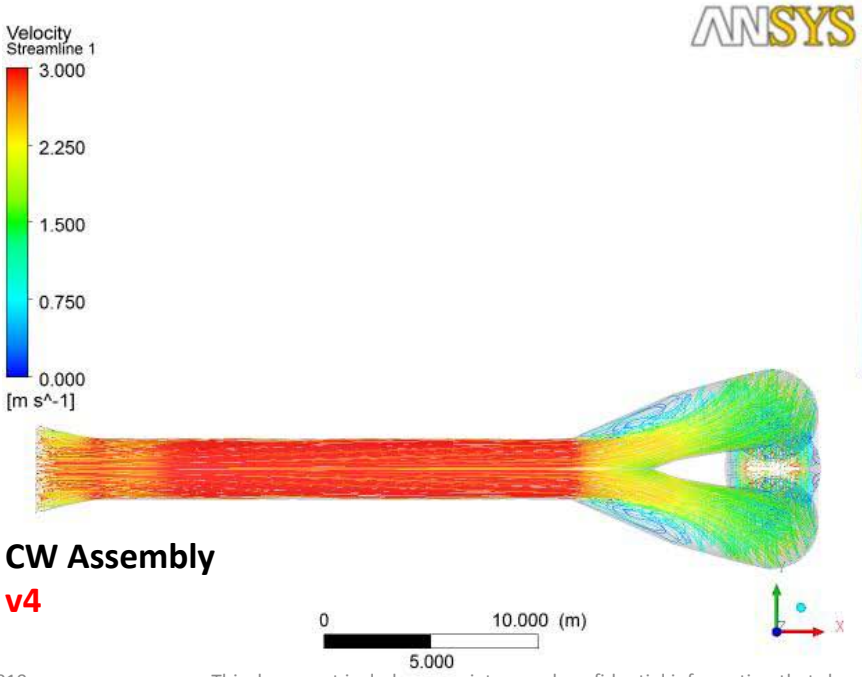
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CW Assembly
v2



CW Assembly
v3

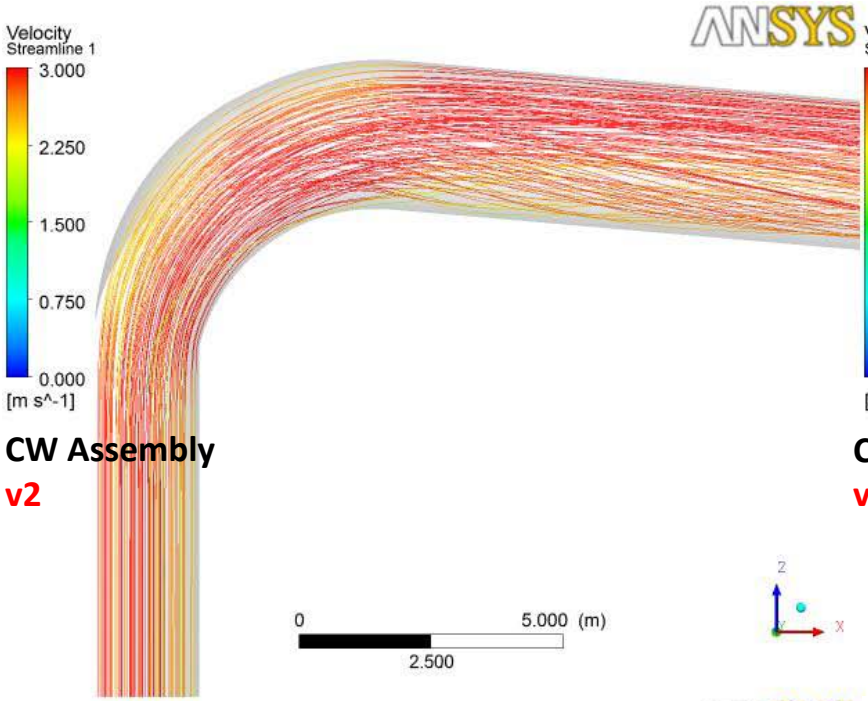


CW Assembly
v4

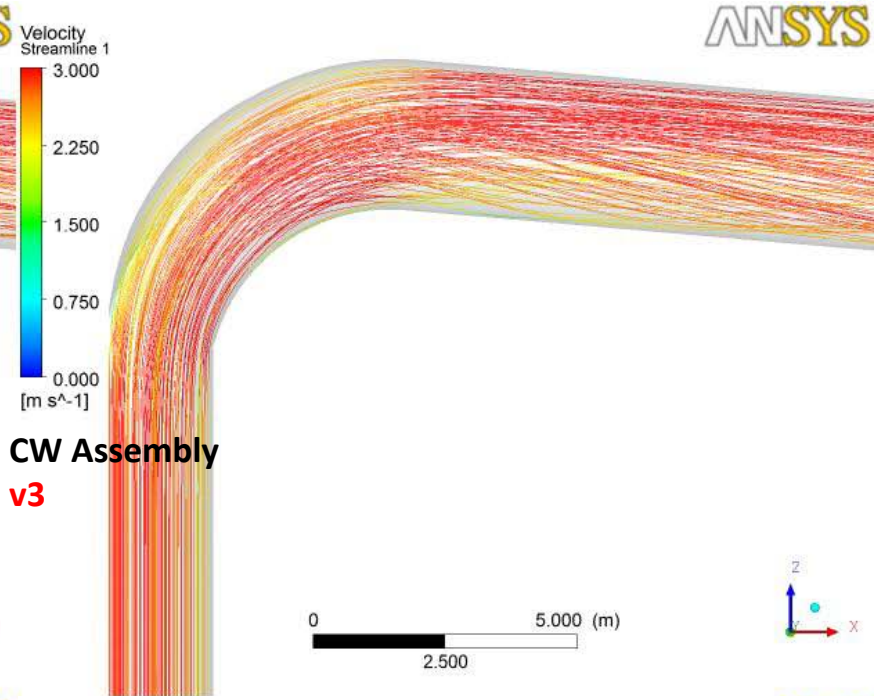
Velocity Streamlines

(View normal to XY plane)

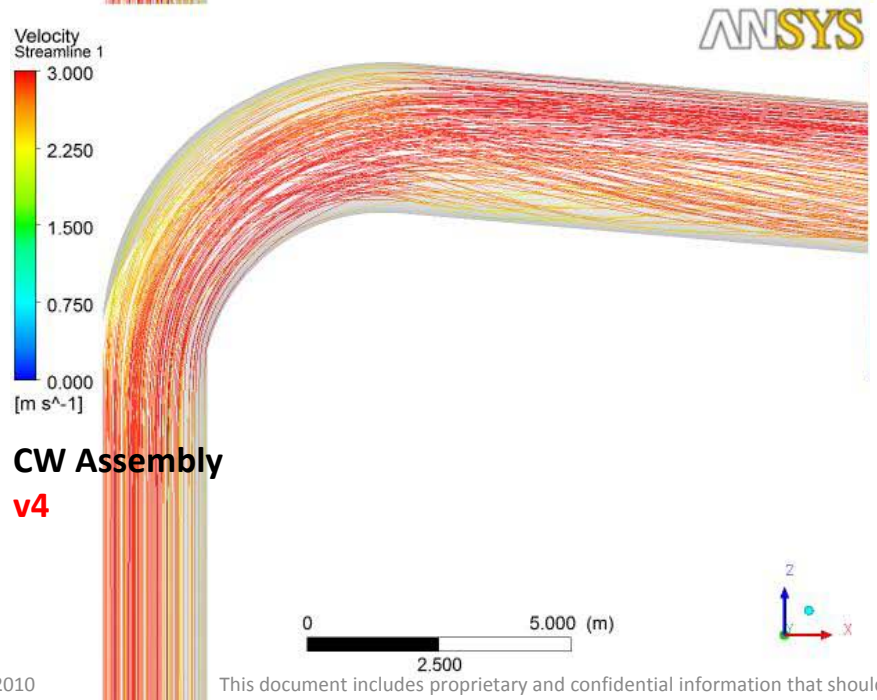
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CW Assembly
v2



CW Assembly
v3

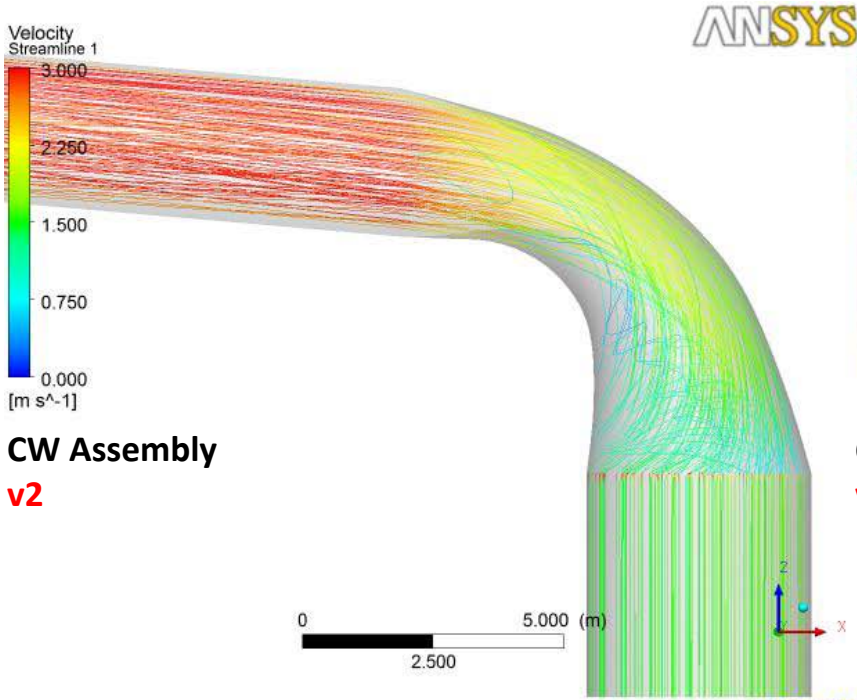


CW Assembly
v4

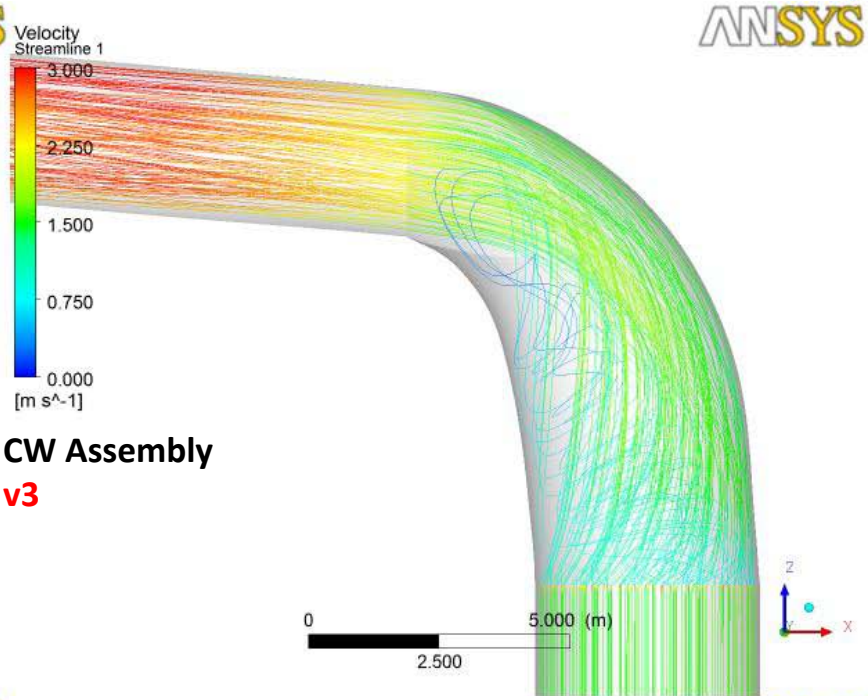
Velocity Streamlines

(View normal to XZ plane, close-up of bend leading to cross-connect duct)

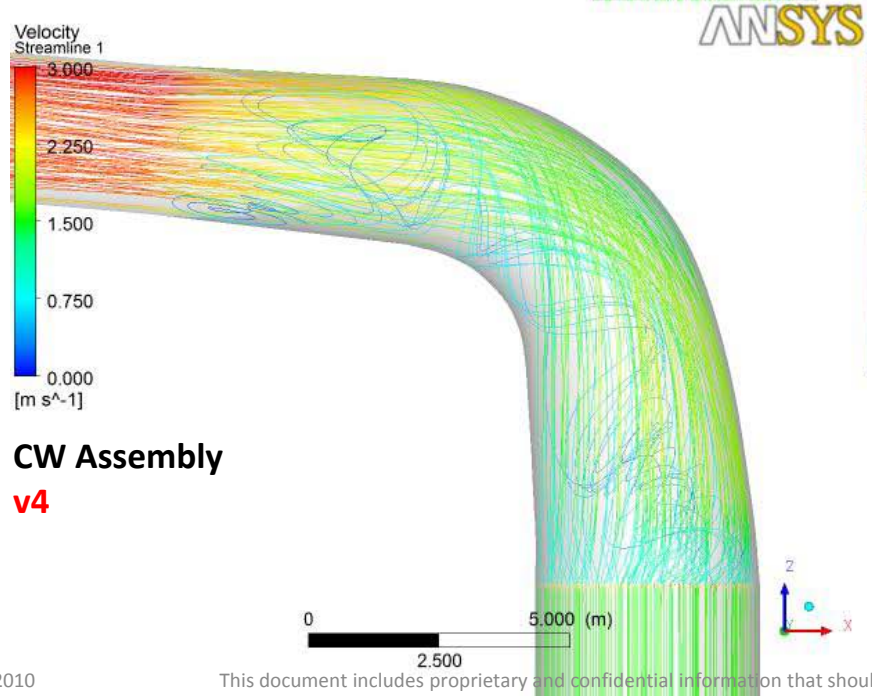
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CW Assembly
v2



CW Assembly
v3

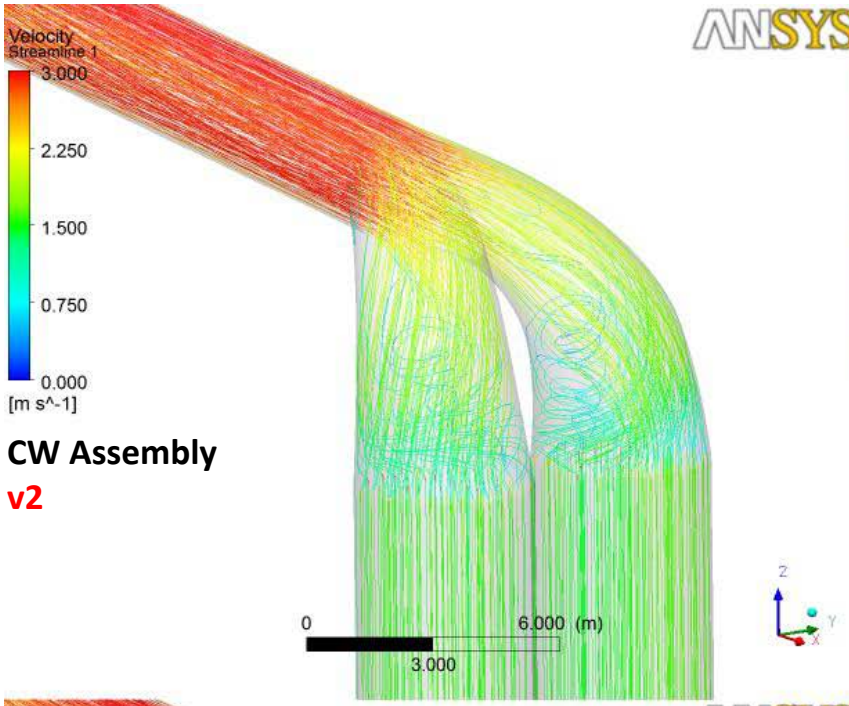


CW Assembly
v4

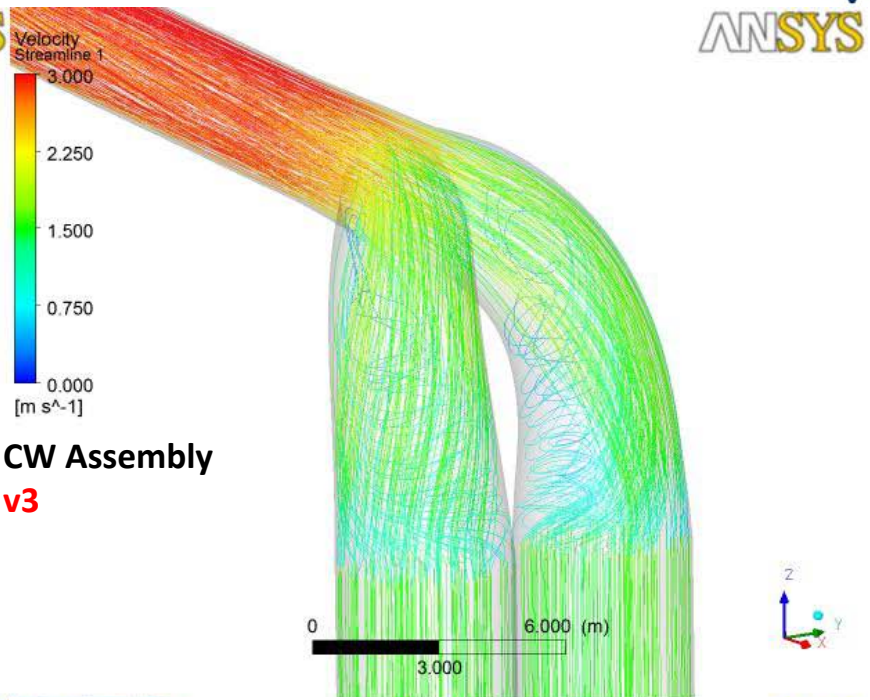
Velocity Streamlines

(View normal to XZ plane, close-up of split and bend leading to heat exchanger)

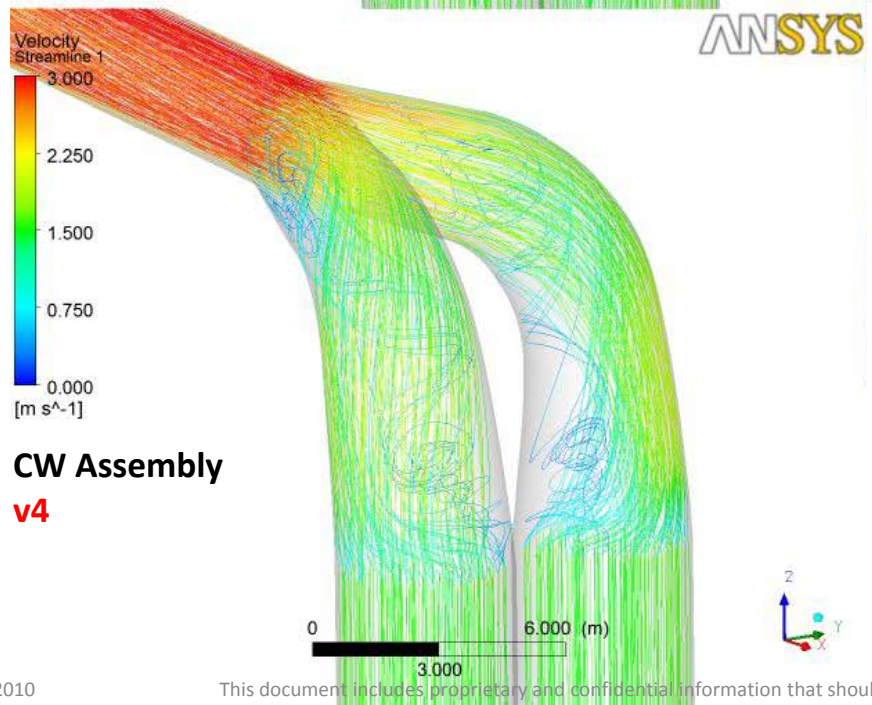
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CW Assembly
v2



CW Assembly
v3

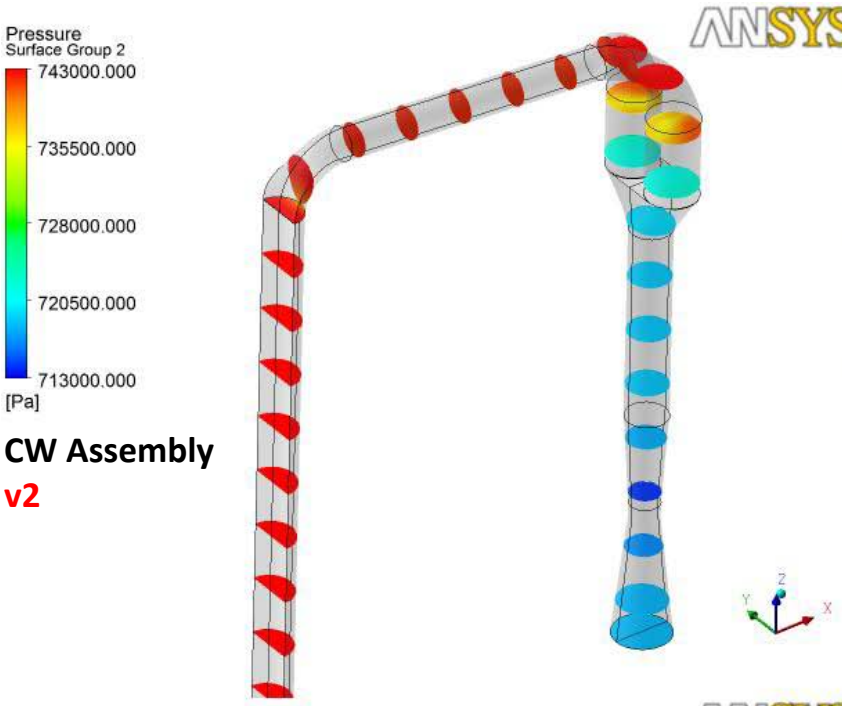


CW Assembly
v4

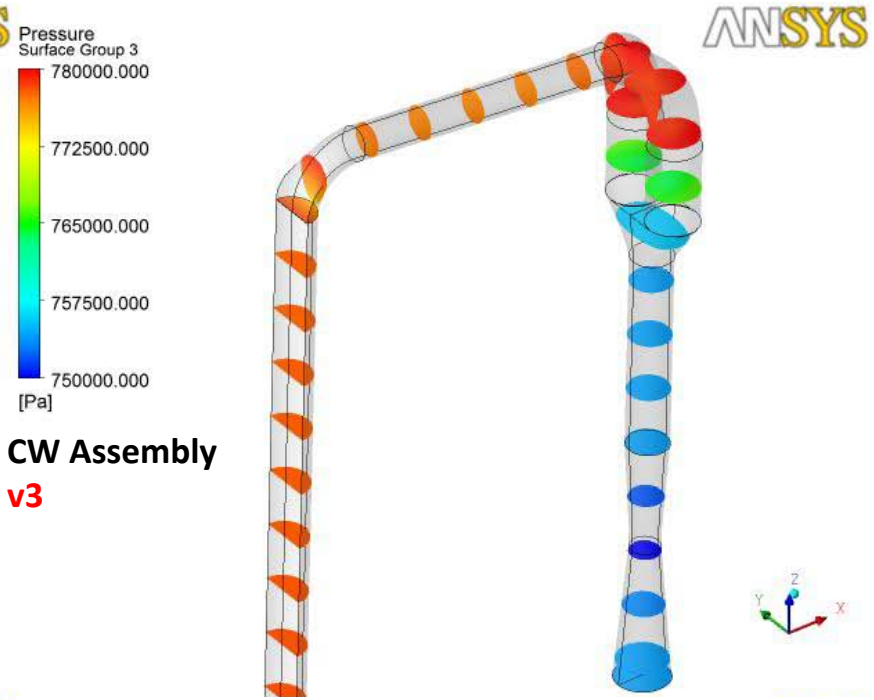
Velocity Streamlines

(3D view, close-up of split and bend leading to heat exchanger)

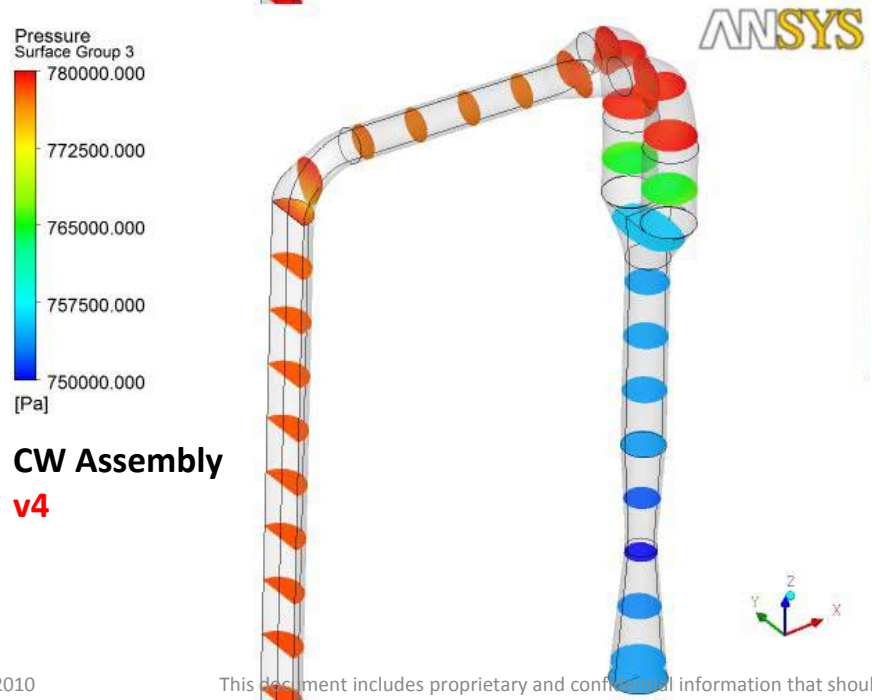
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CW Assembly
v2



CW Assembly
v3

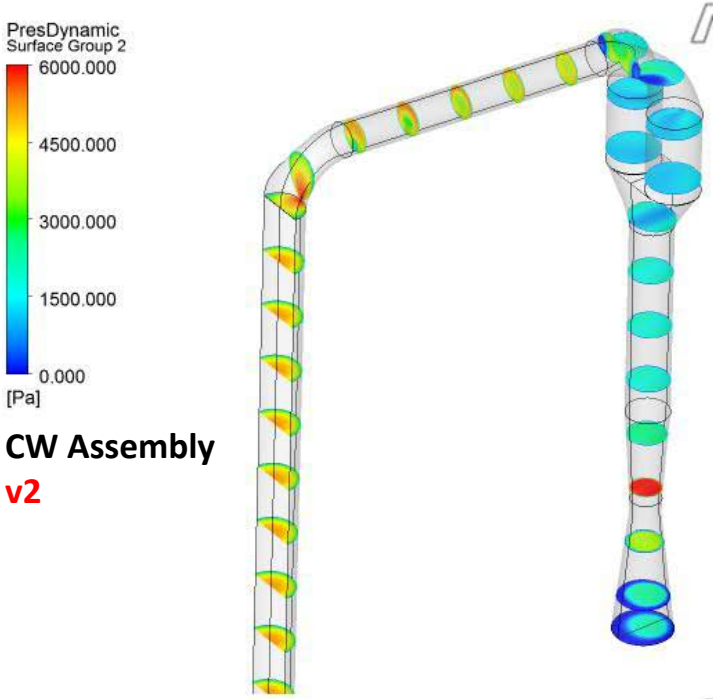


CW Assembly
v4

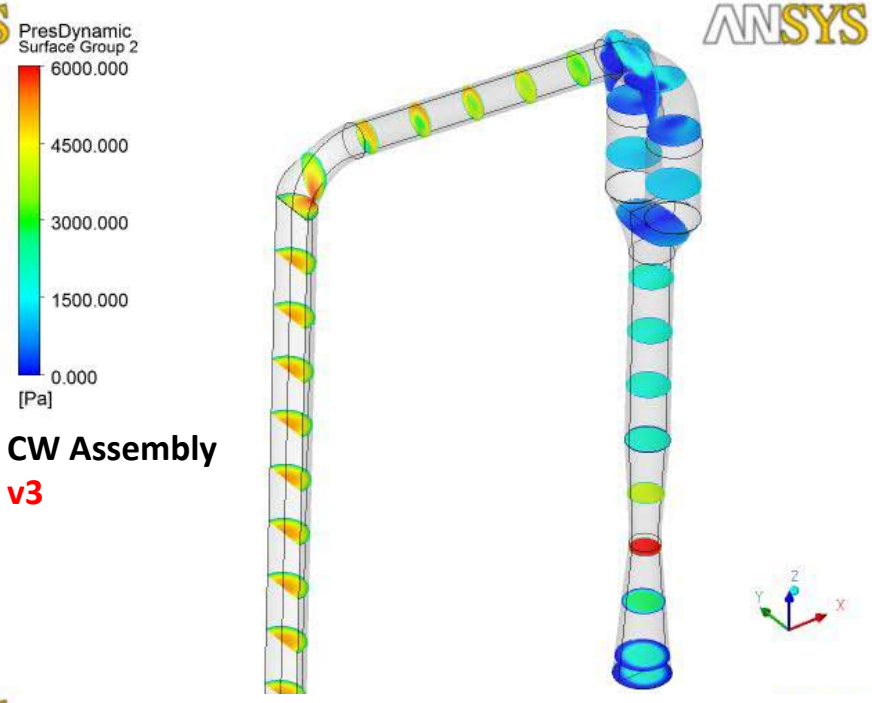
Pressure Cuts: Static Component

(In X and Z every ~5 m)

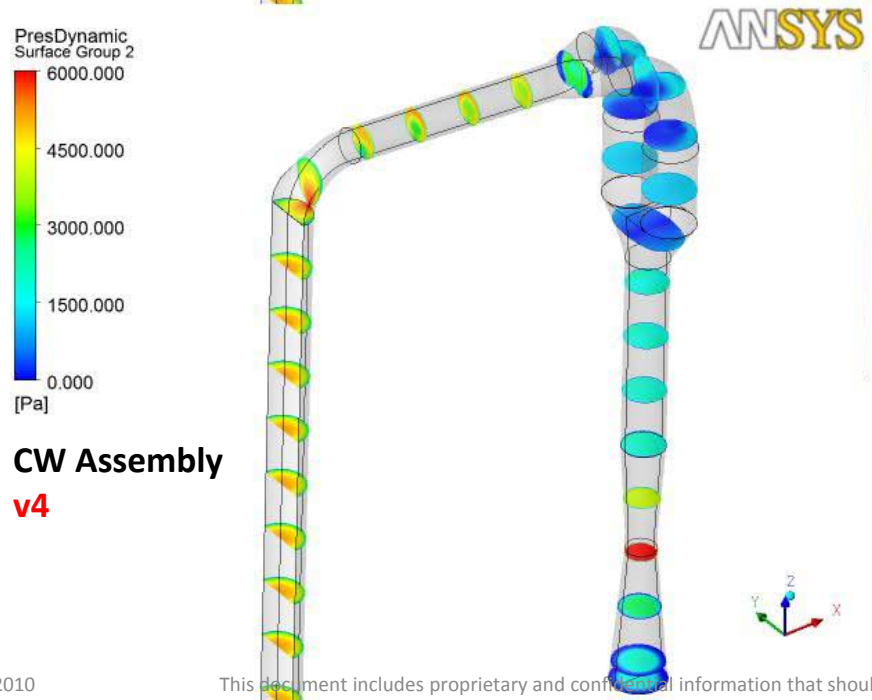
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CW Assembly
v2



CW Assembly
v3

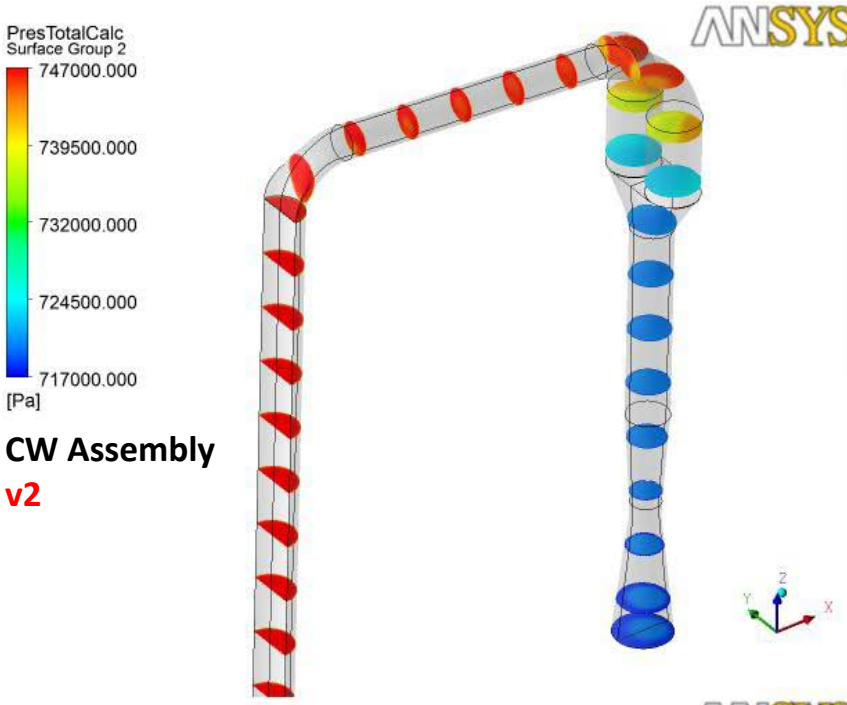


CW Assembly
v4

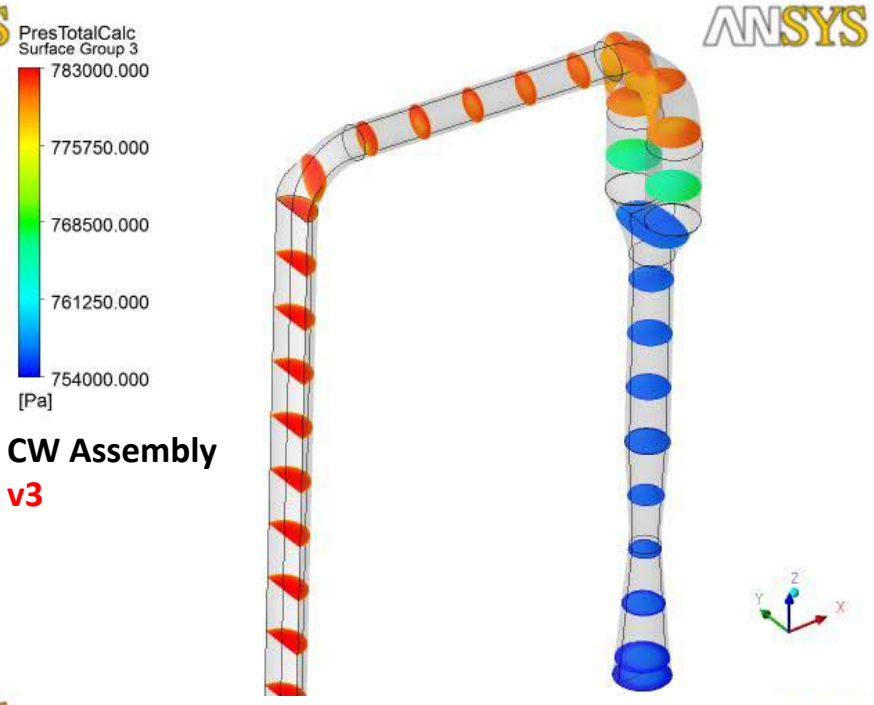
Pressure Cuts: Dynamic Component ($1/2*\rho*v^2$)

(In X and Z every ~5 m)

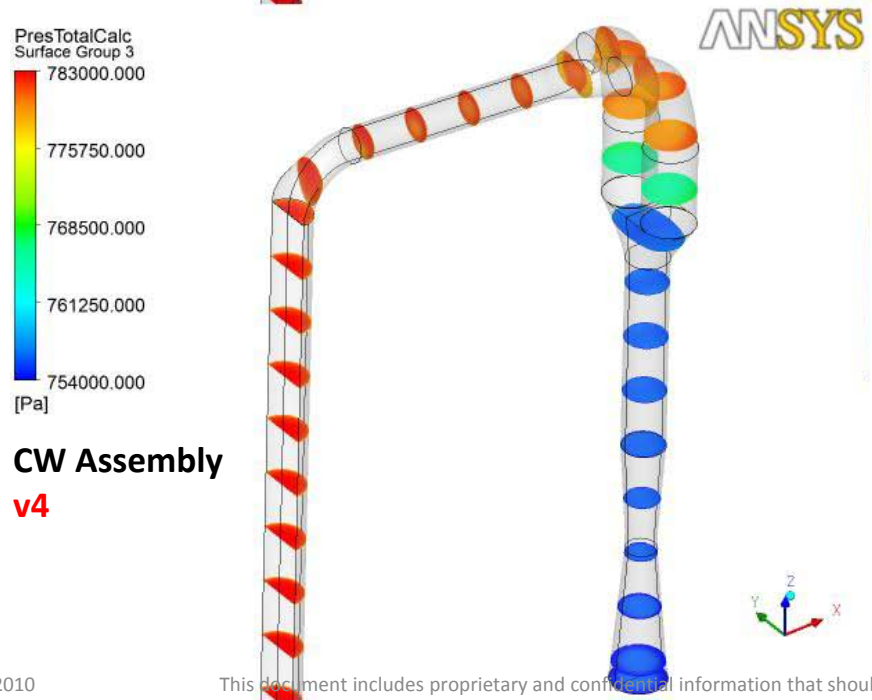
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CW Assembly
v2



CW Assembly
v3

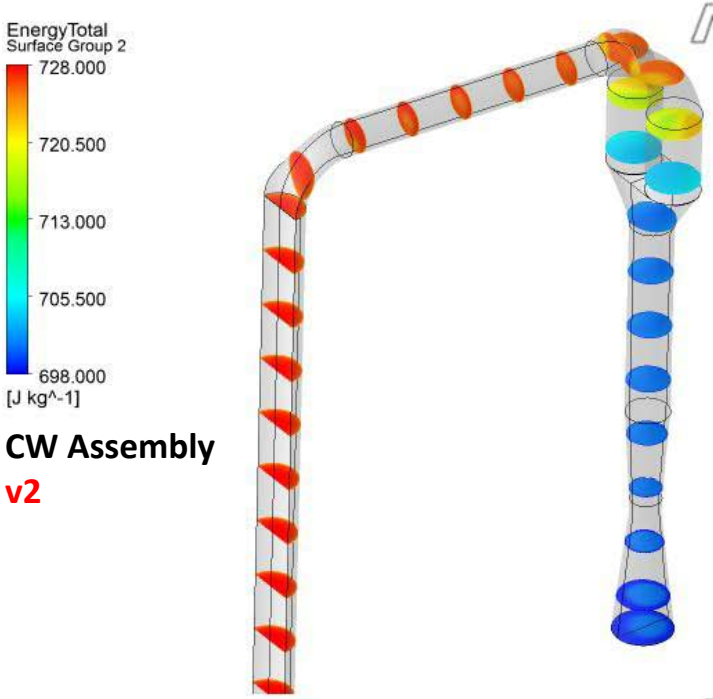


CW Assembly
v4

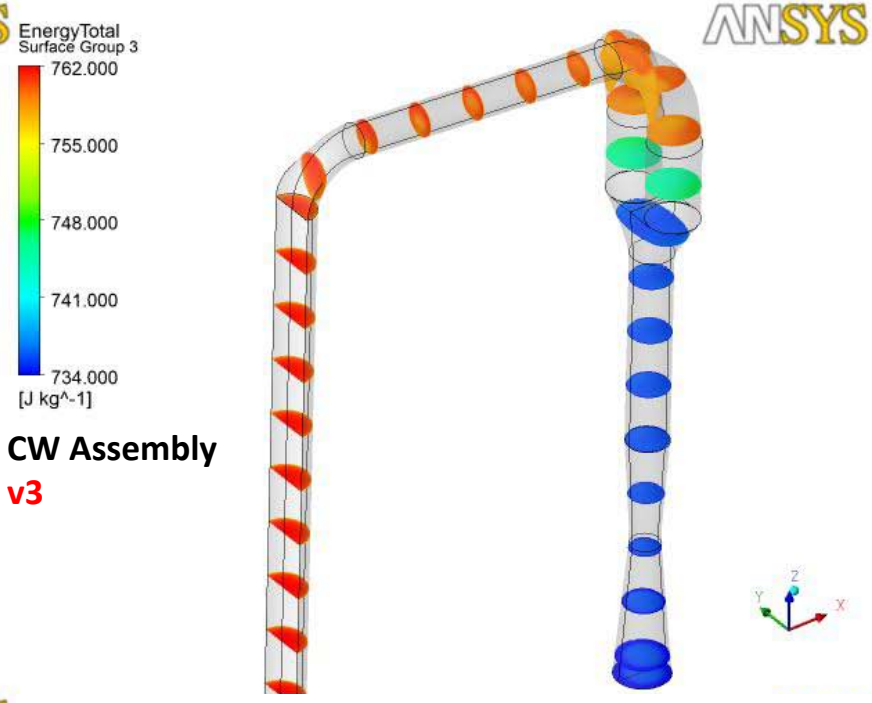
Total Pressure Cuts: Static + Dynamic Components

(In X and Z every ~5 m)

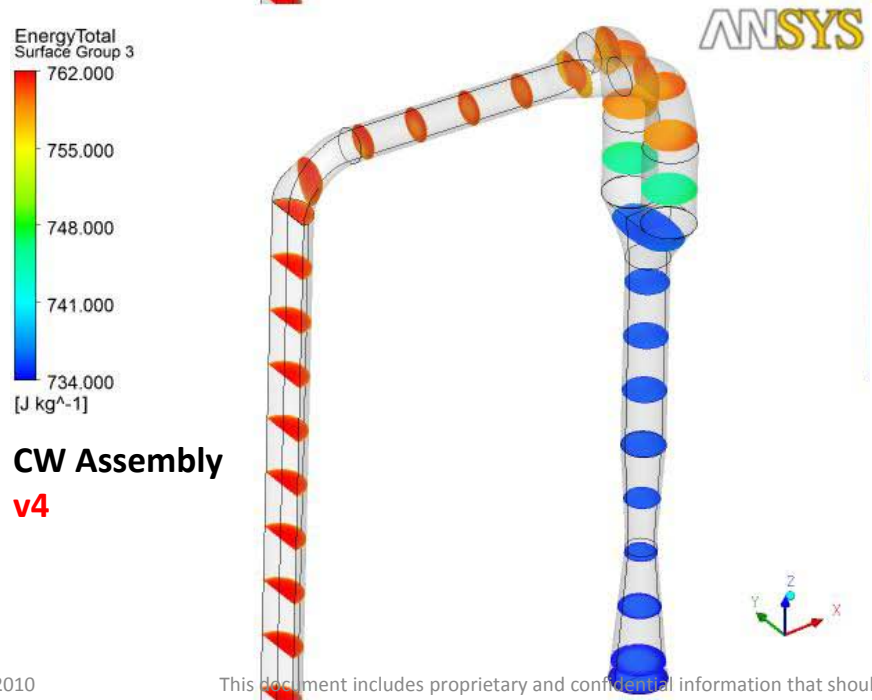
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CW Assembly
v2



CW Assembly
v3

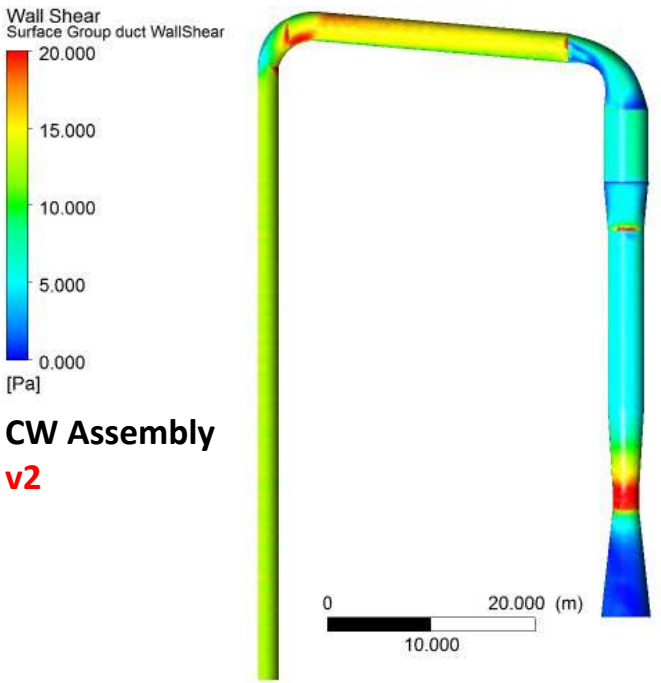


CW Assembly
v4

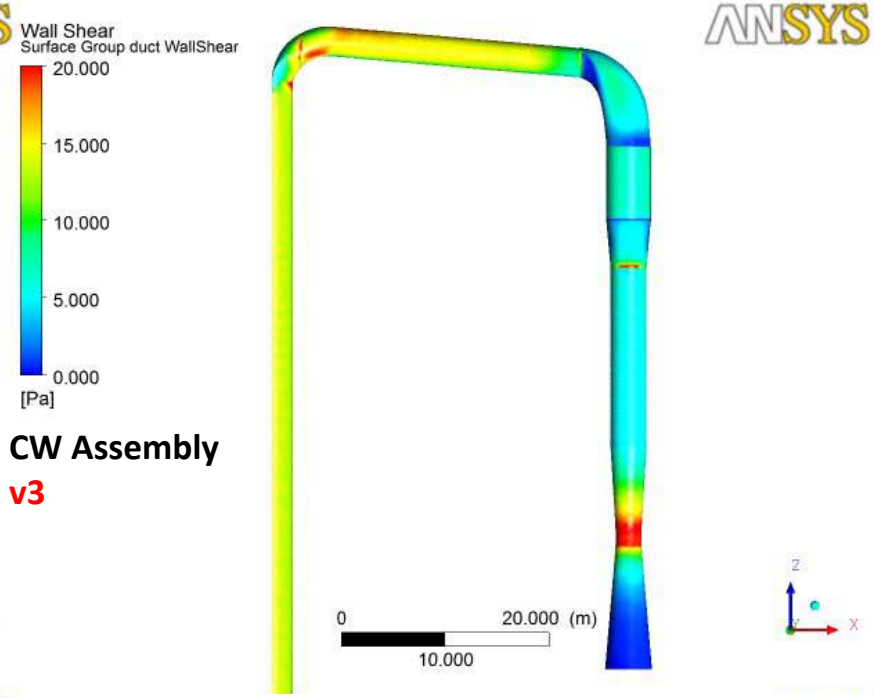
Total Energy per Unit Mass Cuts: Converted from Total Pressure (E = P/ρ)

(In X and Z every ~5 m)

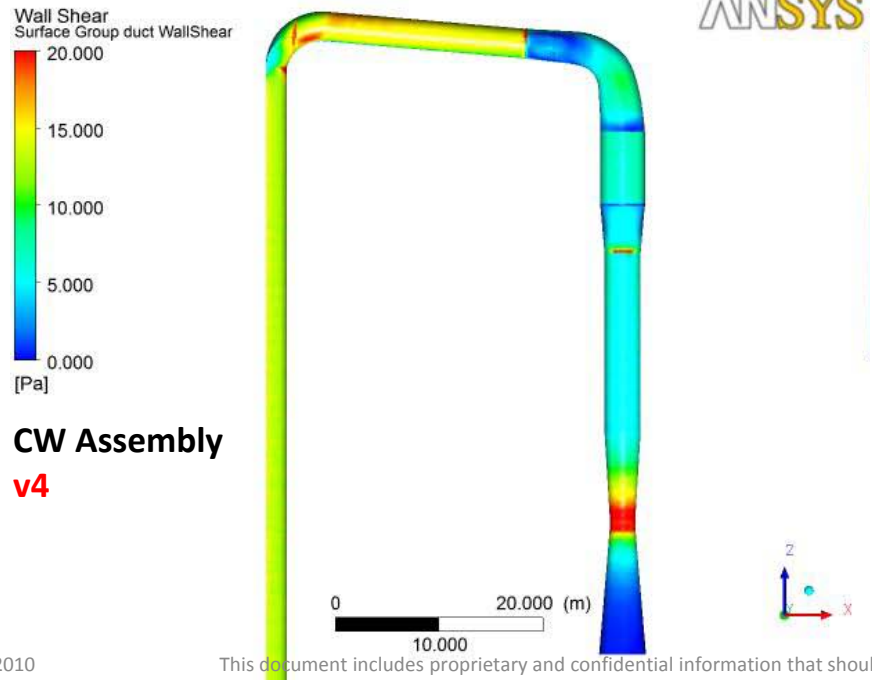
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CW Assembly
v2



CW Assembly
v3



CW Assembly
v4

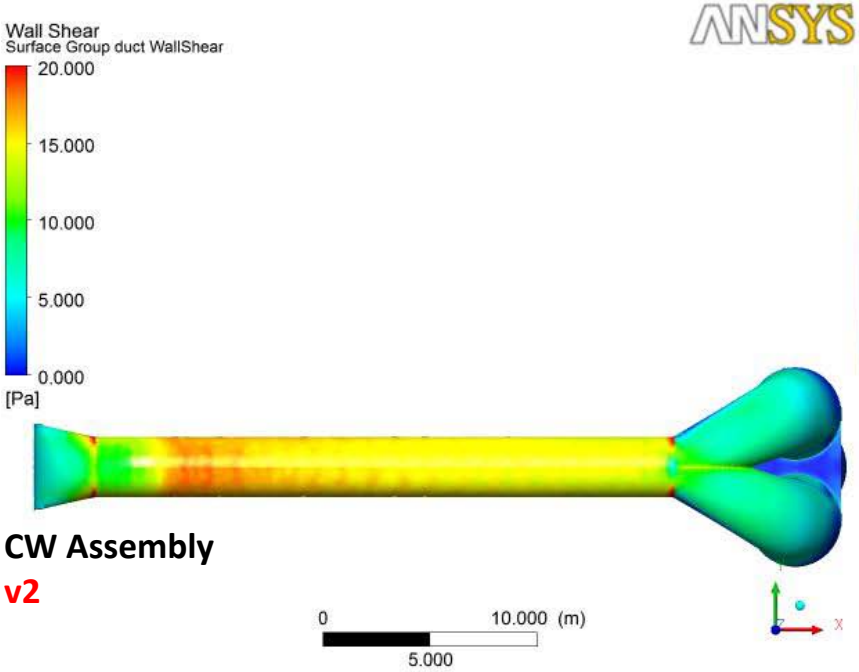
Wall Shear on Pipe Surface

(View normal to XZ plane)

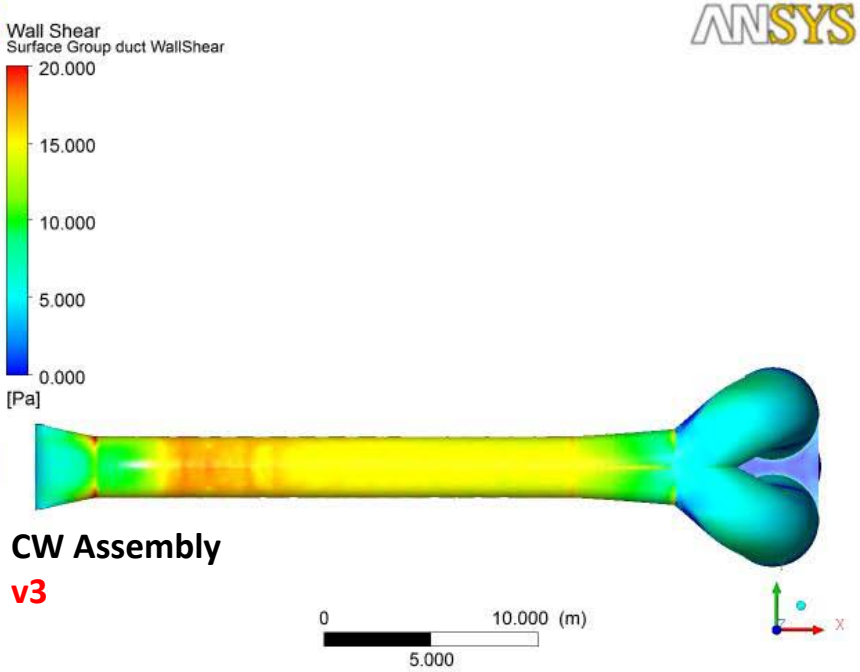
Note:

- Areas of low wall shear can indicate where separation is occurring.

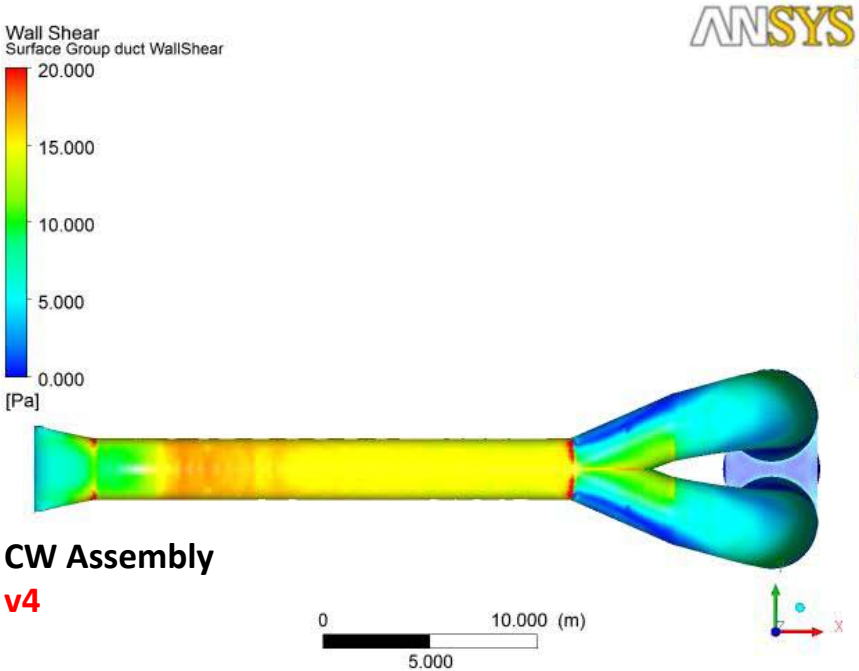
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CW Assembly
v2



CW Assembly
v3

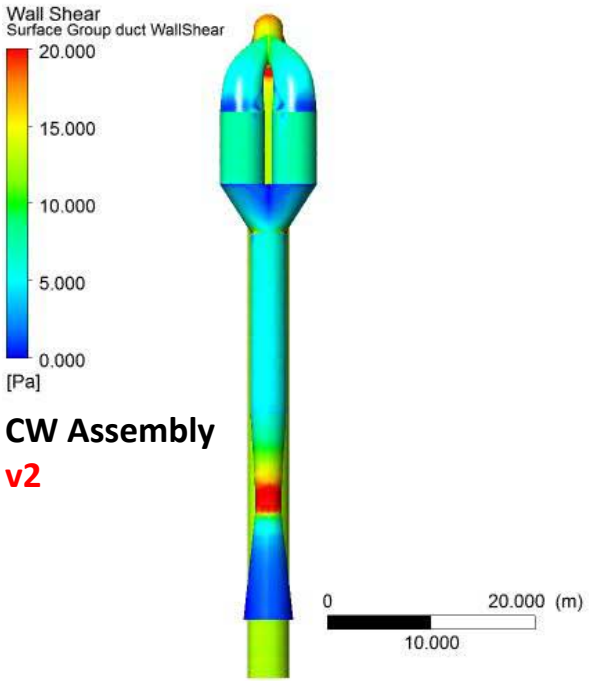


CW Assembly
v4

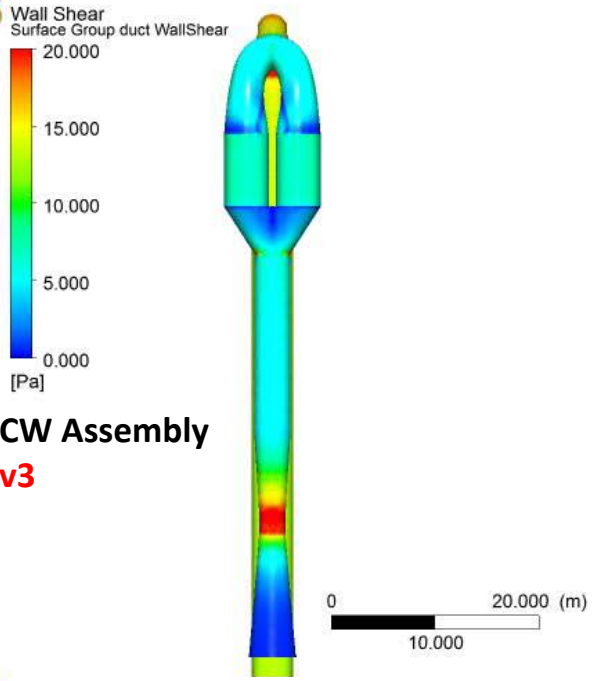
Wall Shear on Pipe Surface

(View normal to XY plane)

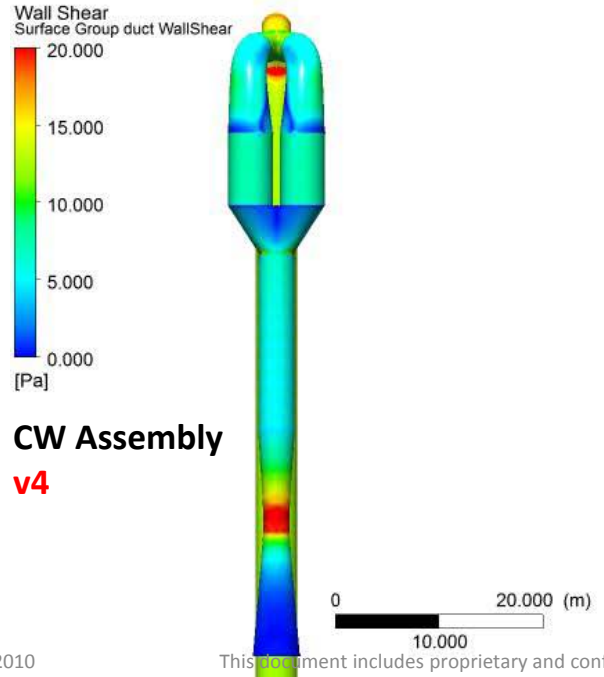
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CW Assembly
v2



CW Assembly
v3

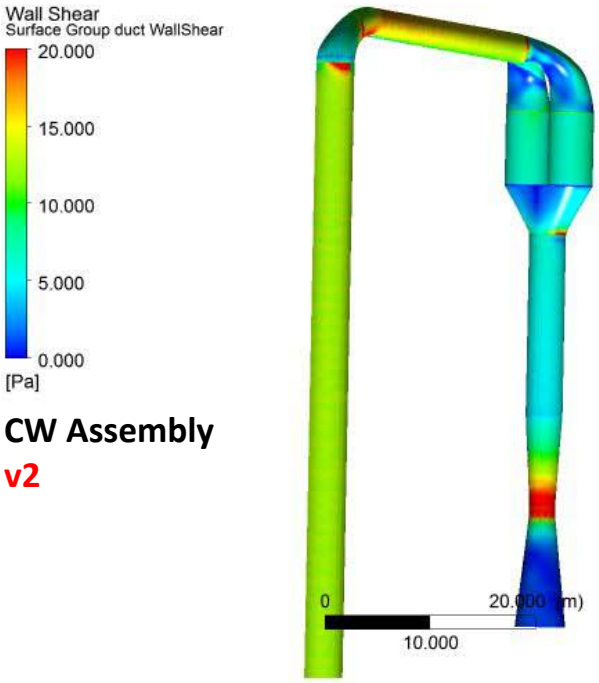


CW Assembly
v4

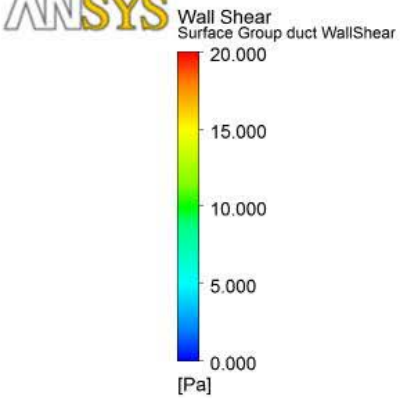
Wall Shear on Pipe Surface

(View normal to YZ plane)

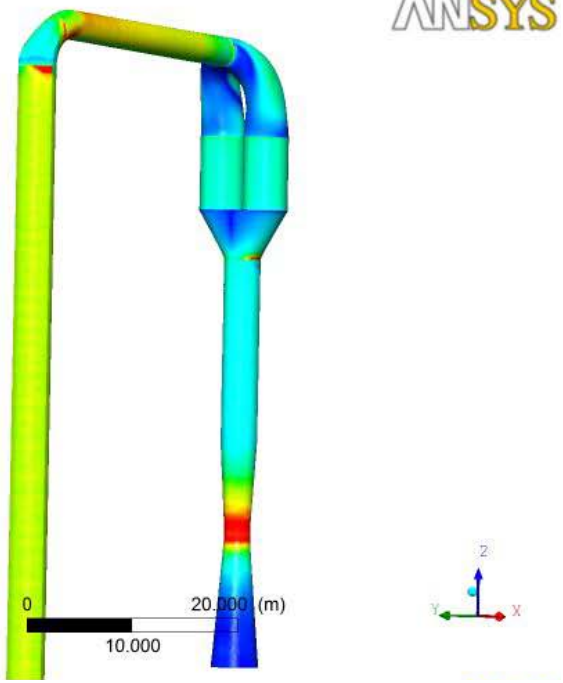
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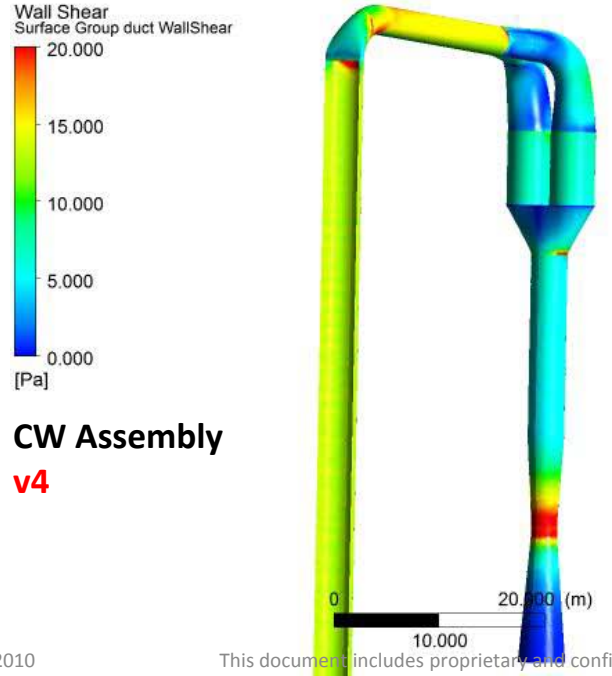


CW Assembly
v2



CW Assembly
v3



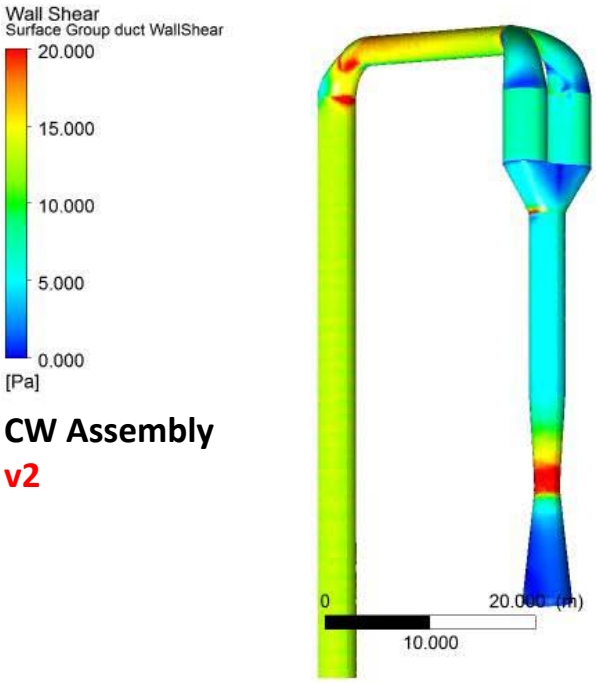


CW Assembly
v4

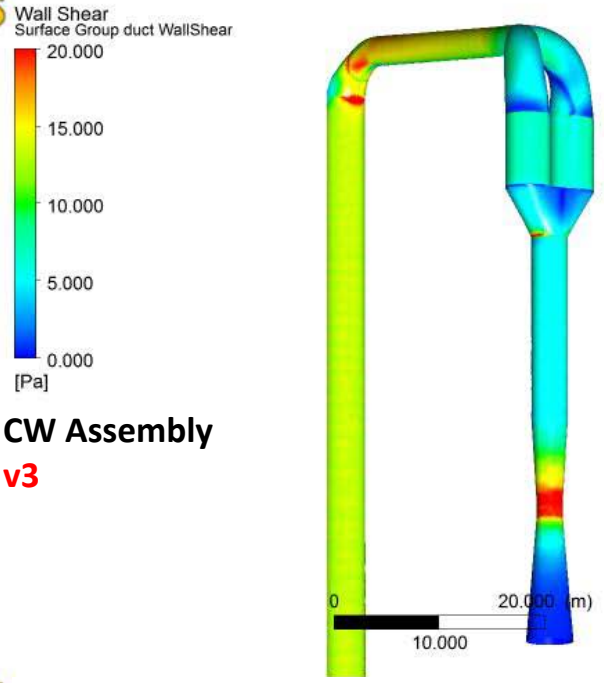
Wall Shear on Pipe Surface

(3D view)

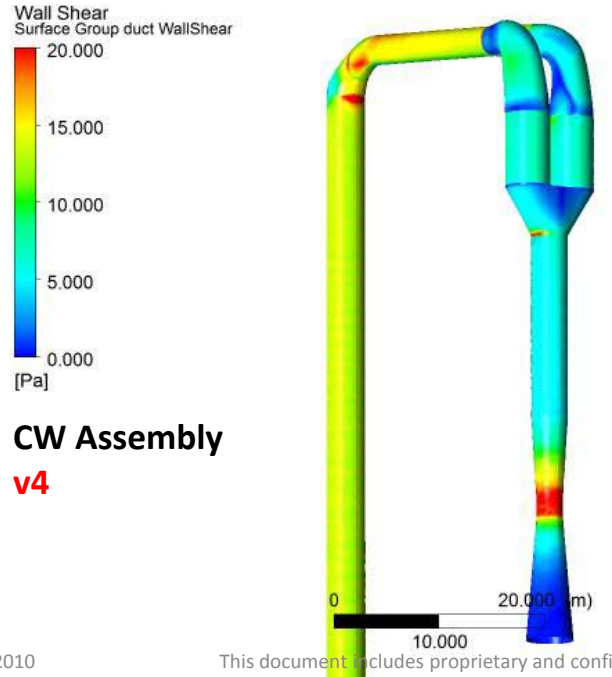
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CW Assembly
v2



CW Assembly
v3



CW Assembly
v4

Wall Shear on Pipe Surface

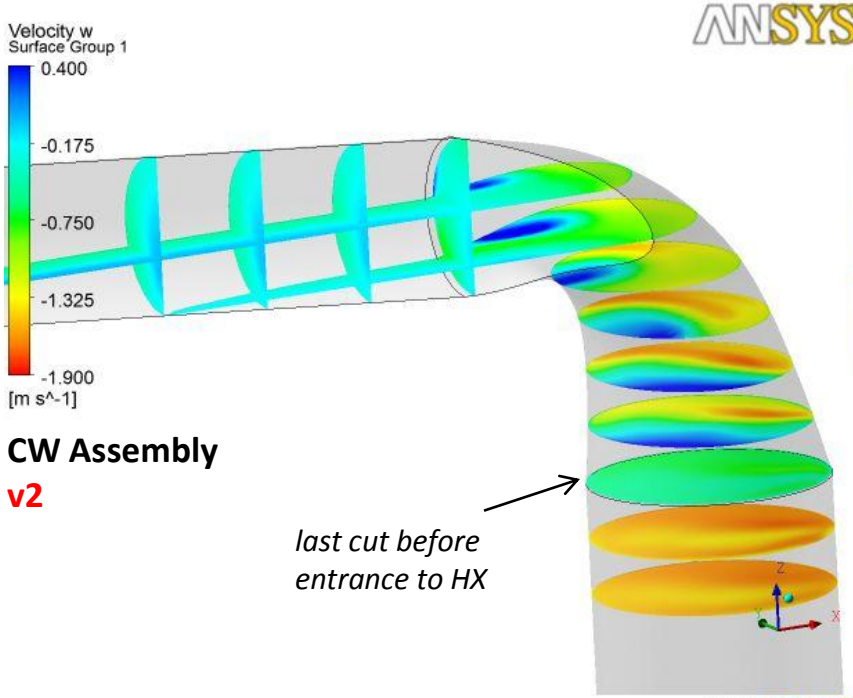
(3D view)

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Summary

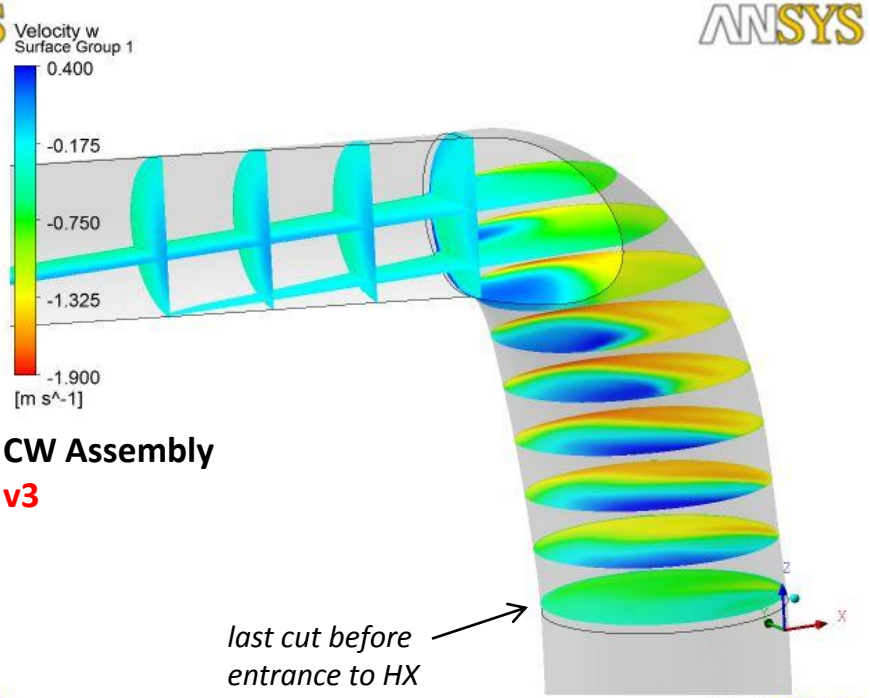
- Flow through bend connecting lead-in duct to cross-over duct:
  - Flow separation still occurs at this bend.
- Flow through cross-connect duct and top piece (CW diffuser manifold, contains split and bend) leading to heat exchanger):
  - The increase in diameter for CW assembly v3 and v4 effectively slowed down the flow velocity through the cross-connect duct and top piece.
  - Vorticity can still be observed in the flow for all versions.
  - The uniformity of flow entering the heat exchanger seems to have improved slightly over CW assembly v2.
  - The pressure drop through the top piece was lowest for CW assembly v3, by ~36% compared to v2 and v4.
- Flow through heat exchanger:
  - Flow is most uniform for CW assembly v4. Flow uniformity in v3 is comparable to v2.
  - The pressure drops across the heat exchanger were slightly lower for CW assembly v3 and v4 compared to v2. This difference is likely due to the lower velocities through the heat exchanger due to the enlarged diffuser.
- Flow at discharge diffuser:
  - Flow at the exit of the CW assembly is most improved in CW assembly v4, and slightly improved in CW assembly v3. Flow is more symmetrical, and recirculation has decreased.
- Summary:
  - The configuration with the lowest losses was CW assembly v3, although flow uniformity through the heat exchanger was comparable to CW assembly v2.
  - The configuration with the most uniform flow across the heat exchanger was CW assembly v4, although losses in the top diffuser piece were comparable to CW assembly v2.
  - The latest version of the diffuser, v2, displayed improved performance over v1.
  - The improved uniformity in flow through the HX observed in CW assembly v4, appeared to carry down through the discharge diffuser. The flow at the exit for this assembly contained the least amount of recirculation and was more uniform over the cross-section.

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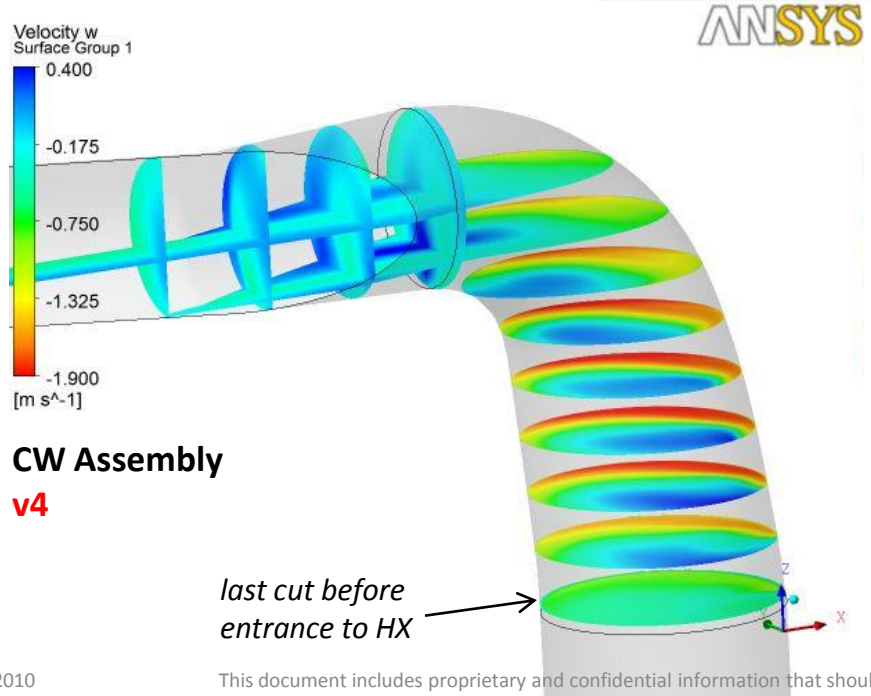
CW Assembly
v2

last cut before entrance to HX



CW Assembly
v3

last cut before entrance to HX



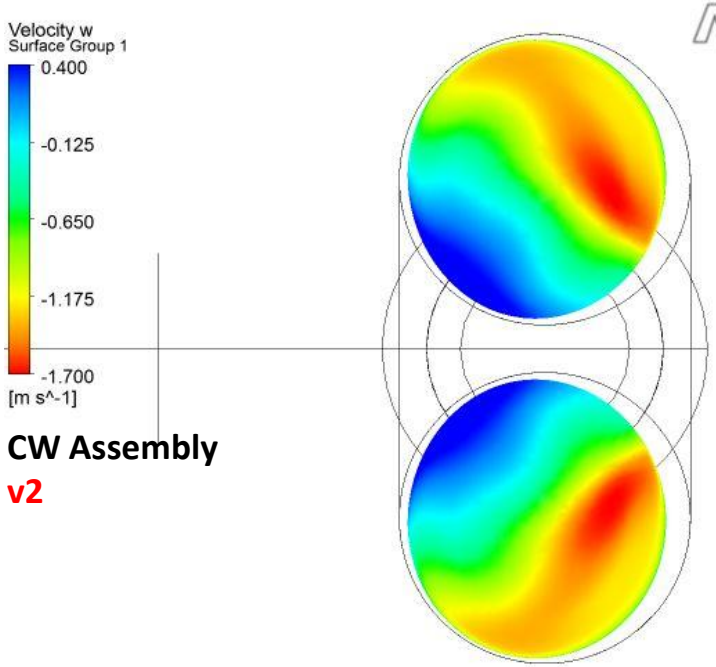
CW Assembly
v4

last cut before entrance to HX

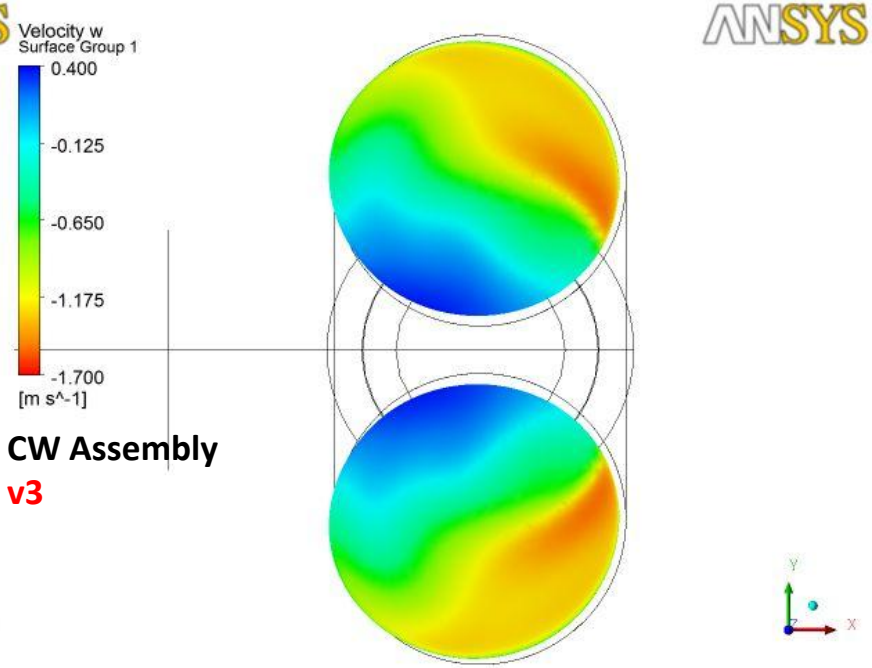
Velocity W, Cuts in X and Z

(Cuts in X spaced 2m apart, cuts in Z spaced 1m apart)

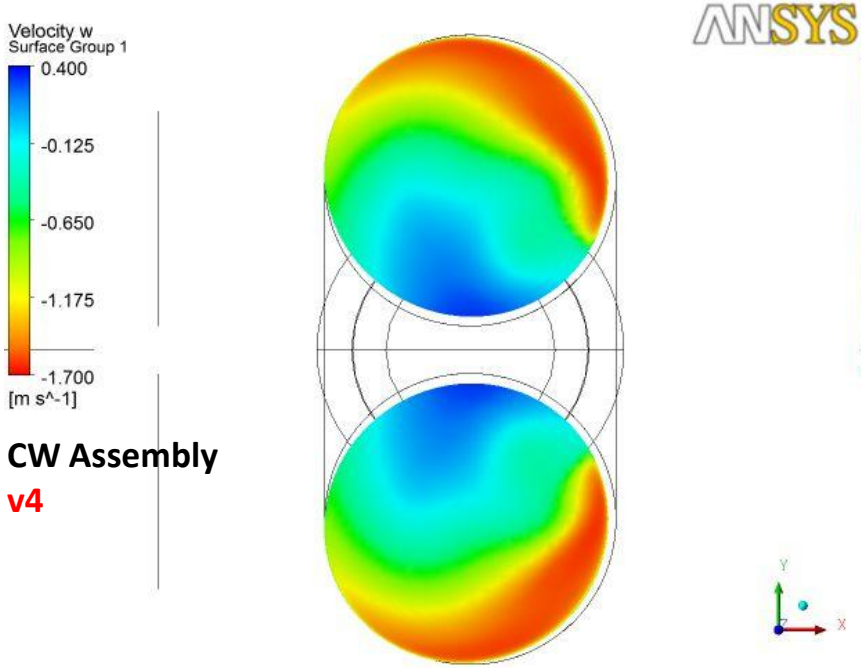
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CW Assembly
v2



CW Assembly
v3



CW Assembly
v4

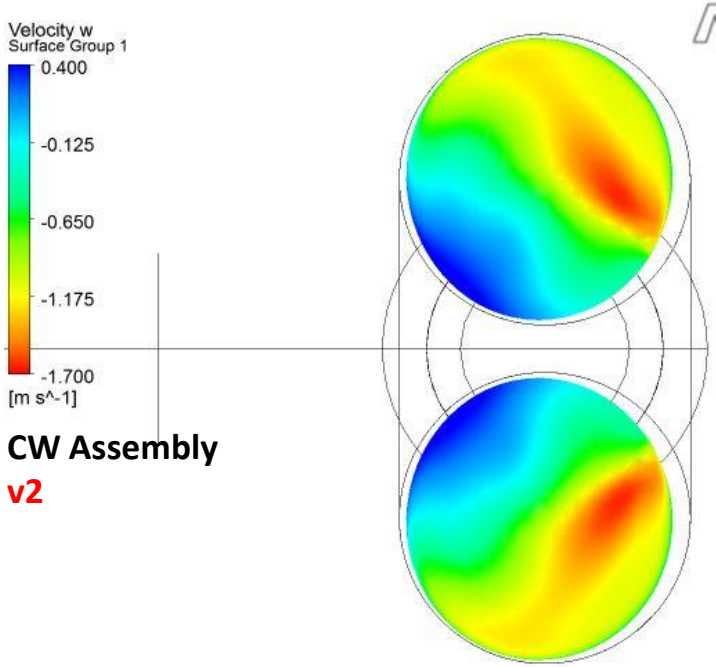
Velocity W, Cuts in Z 1.2 m above Entrance to HX

(Normal to XY plane)

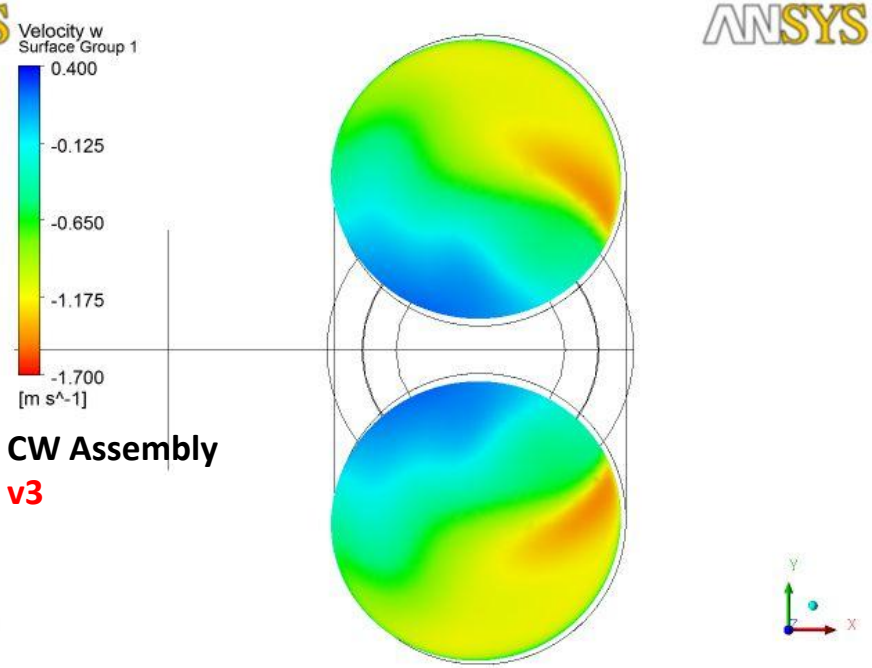
Note:

- Up is positive, down is negative

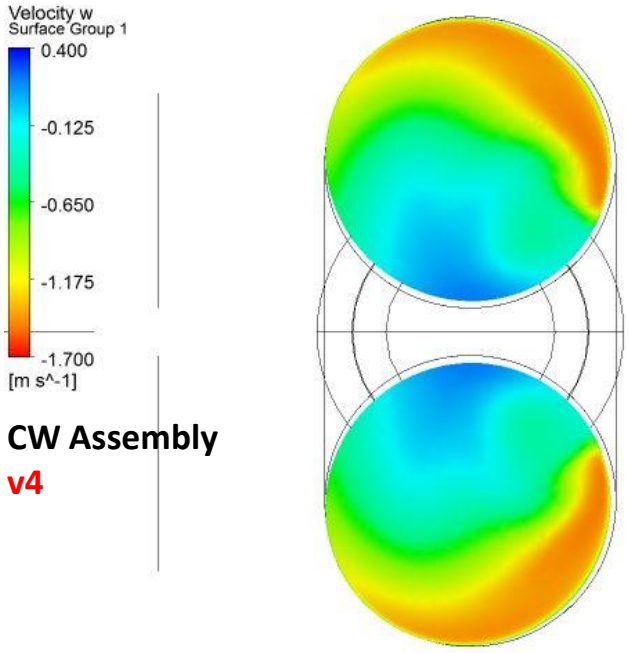
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CW Assembly
v2



CW Assembly
v3



CW Assembly
v4

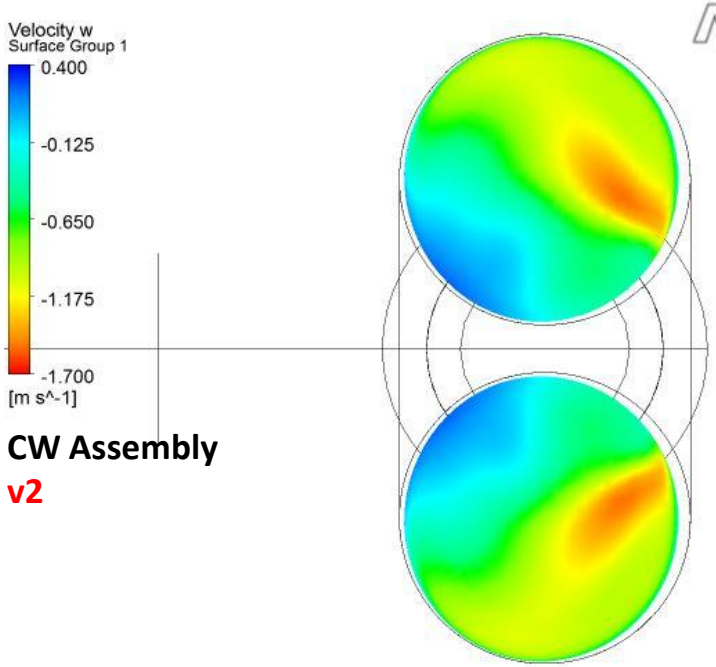
Velocity W, Cuts in Z 0.9 m above Entrance to HX

(Normal to XY plane)

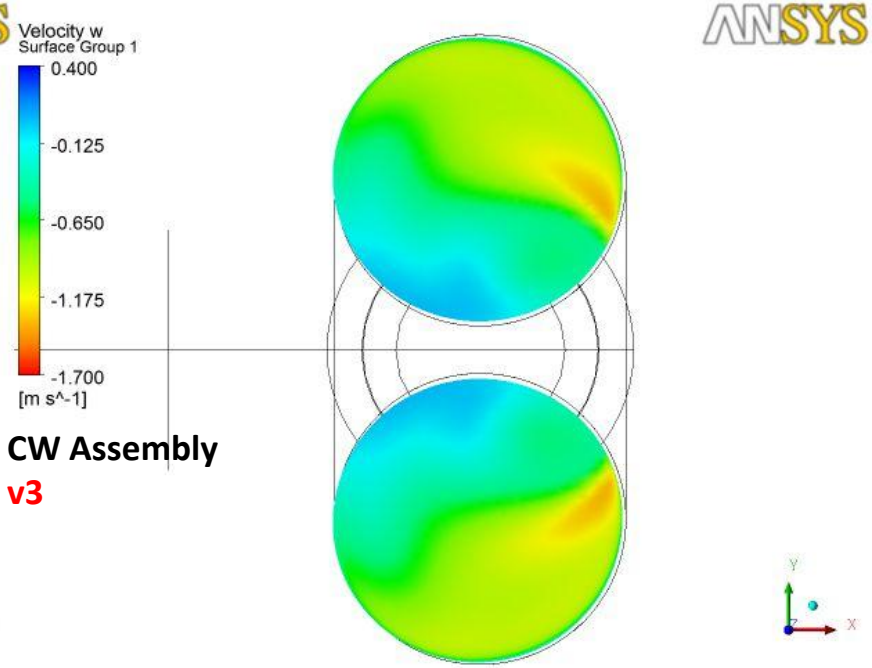
Note:

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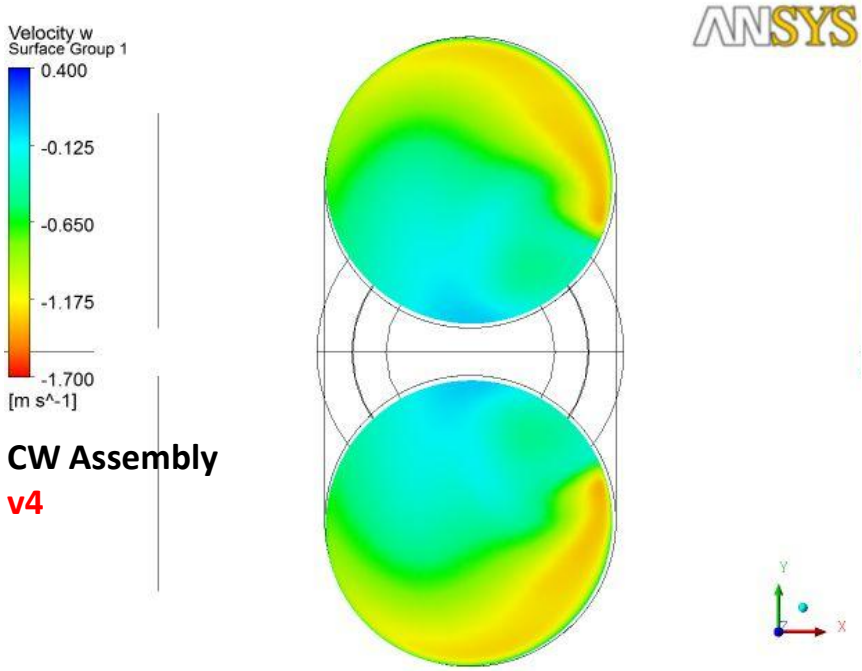
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CW Assembly
v2



CW Assembly
v3



CW Assembly
v4

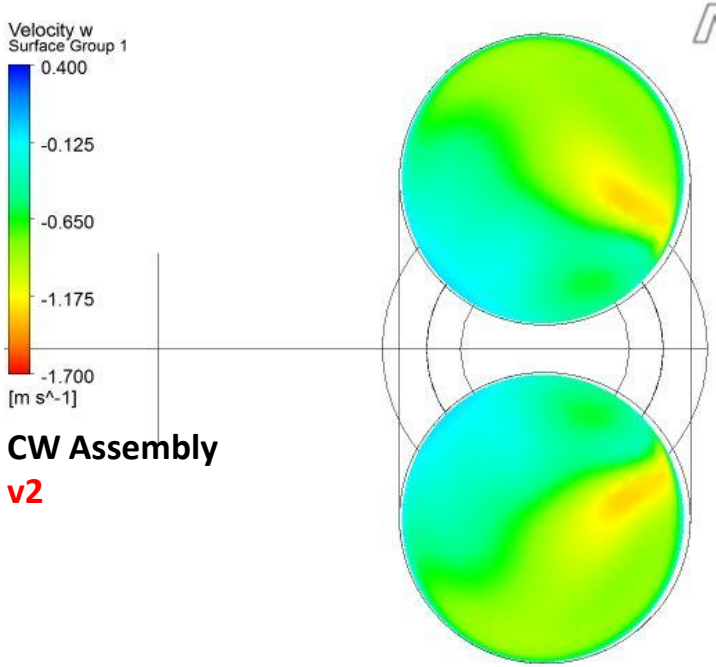
Velocity W, Cuts in Z 0.6 m above Entrance to HX

(Normal to XY plane)

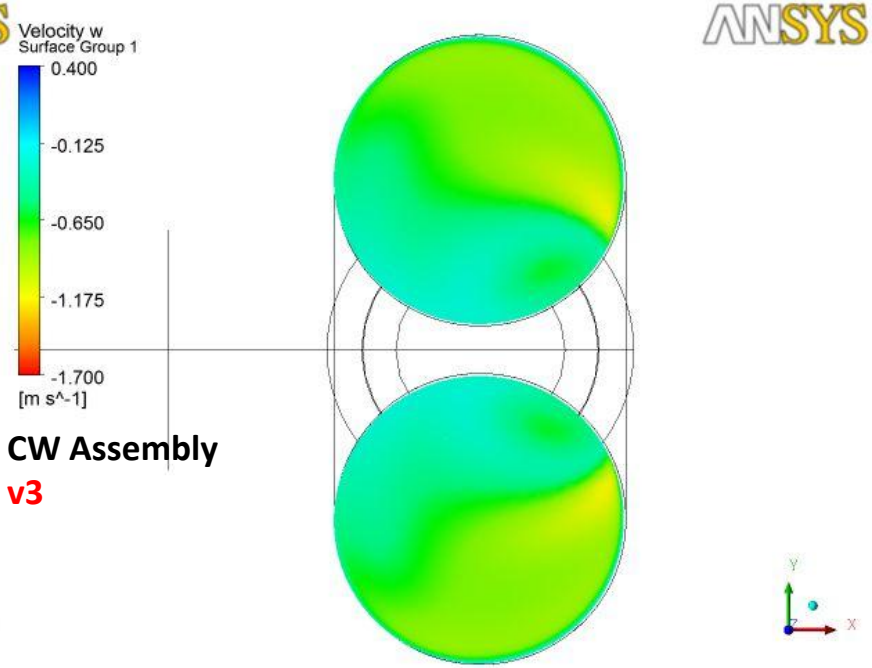
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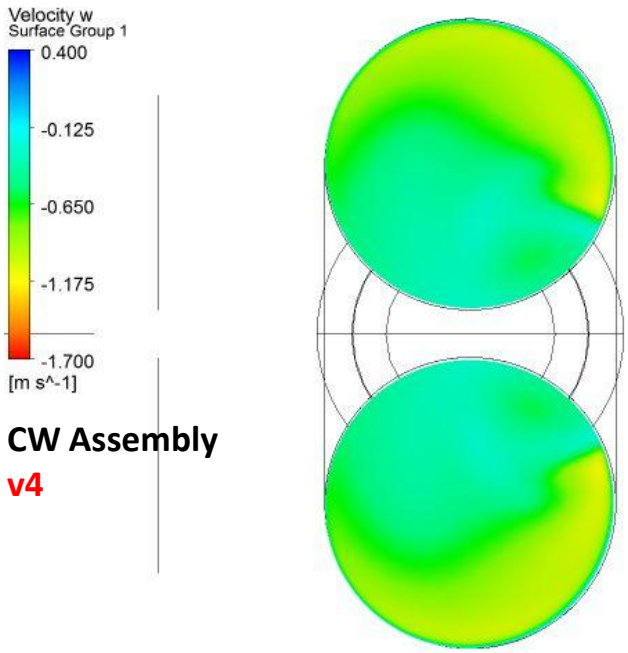
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CW Assembly
v2



CW Assembly
v3



CW Assembly
v4

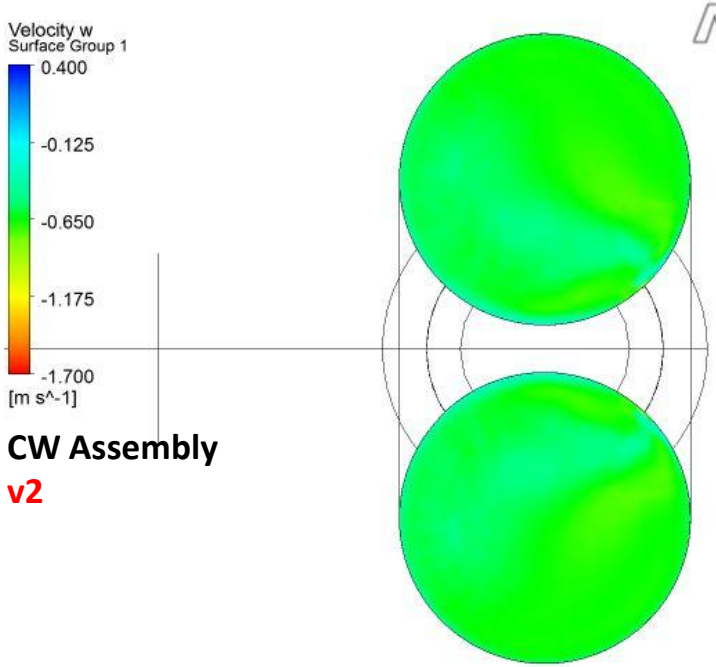
Velocity W, Cuts in Z 0.3 m above Entrance to HX

(Normal to XY plane)

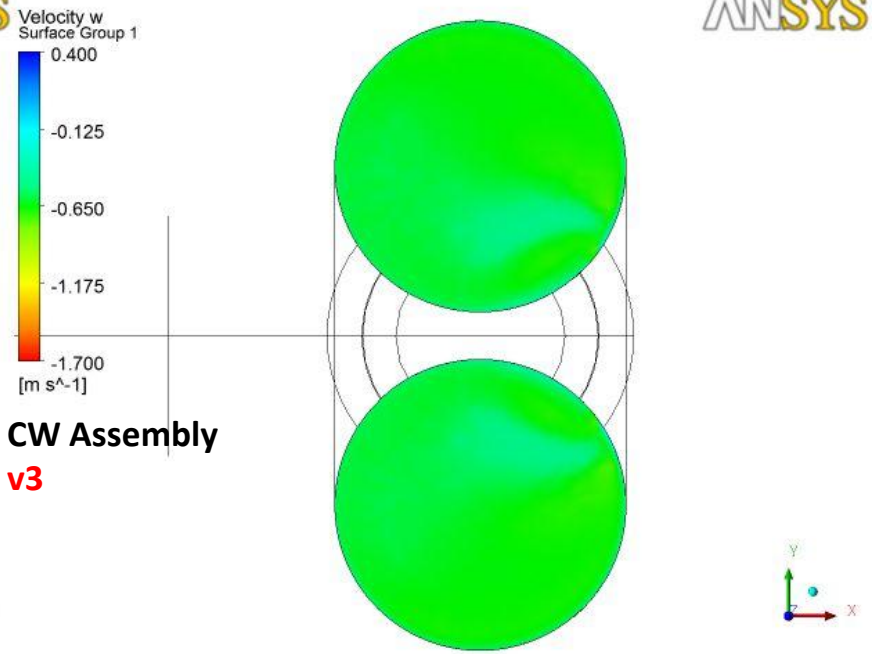
Note:

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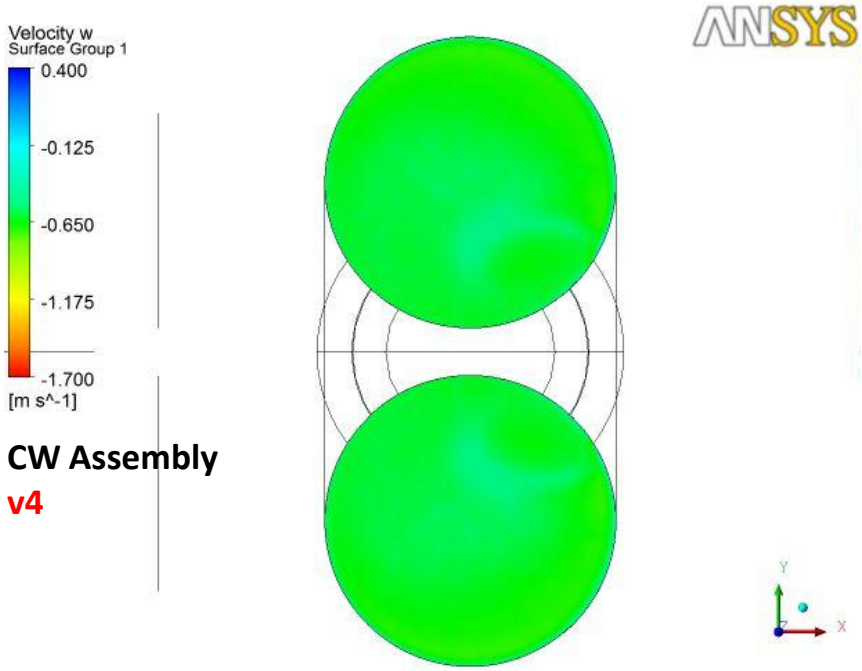
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CW Assembly
v2



CW Assembly
v3



CW Assembly
v4

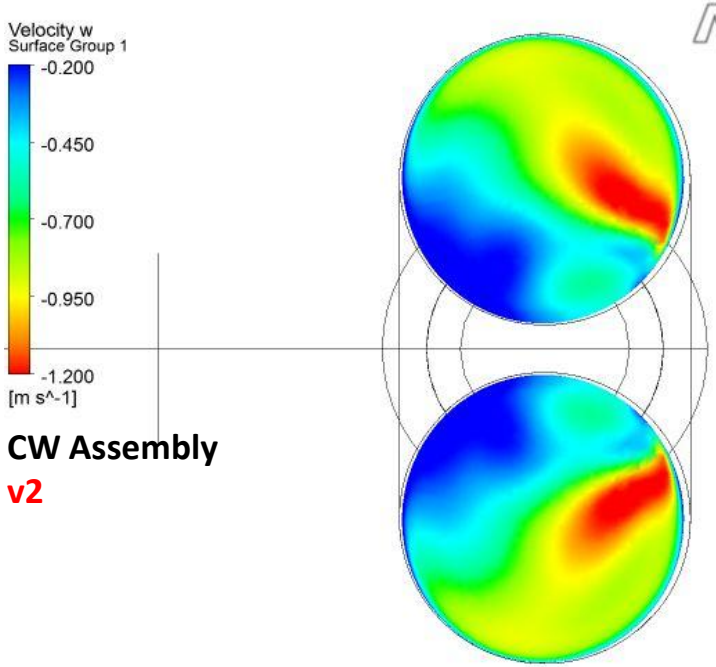
Velocity W, Cuts in Z 0.0 m above Entrance to HX

(Normal to XY plane)

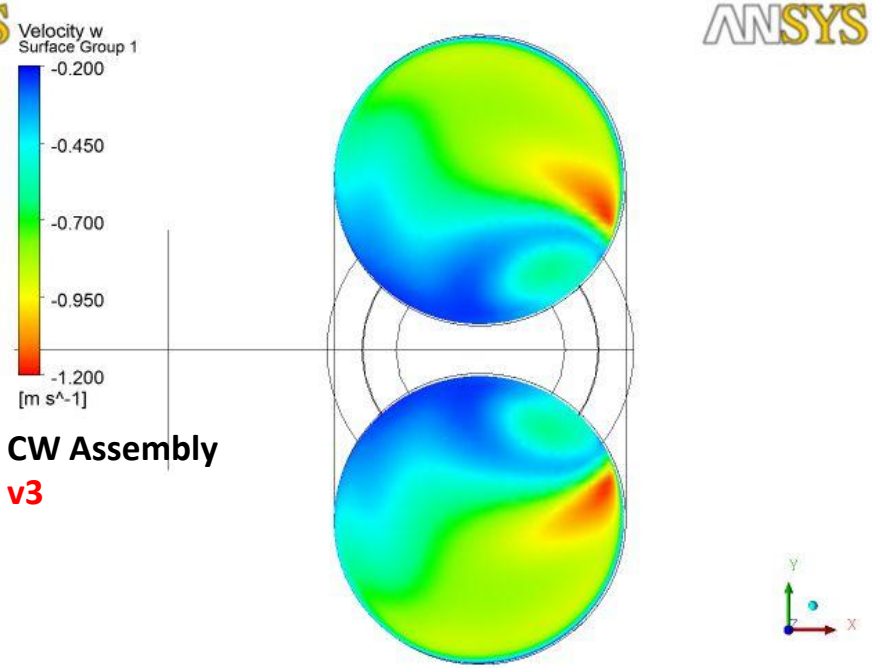
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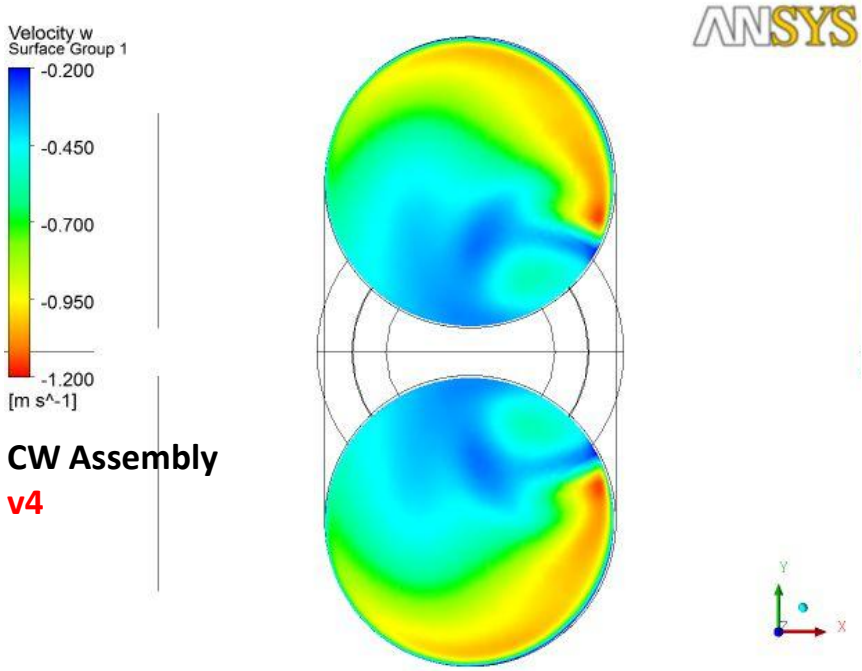
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CW Assembly
v2



CW Assembly
v3



CW Assembly
v4

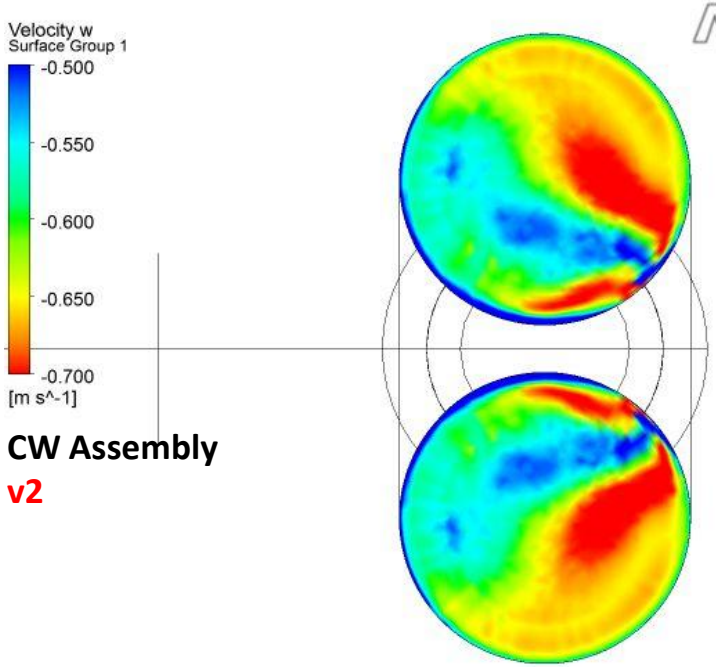
Velocity W, Cuts in Z 0.3 m above Entrance to HX, Narrowed Color Scale

(Normal to XY plane)

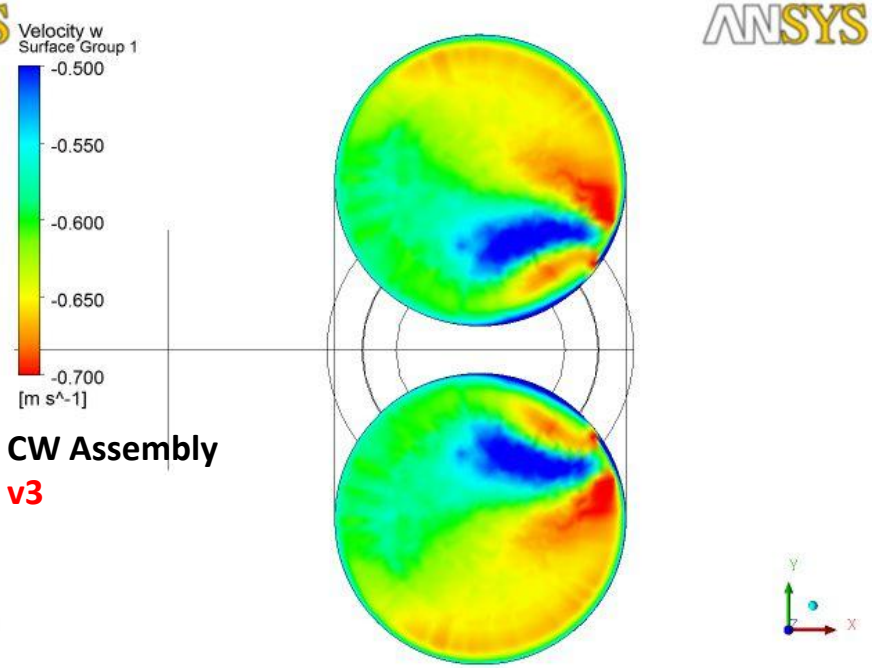
Note:

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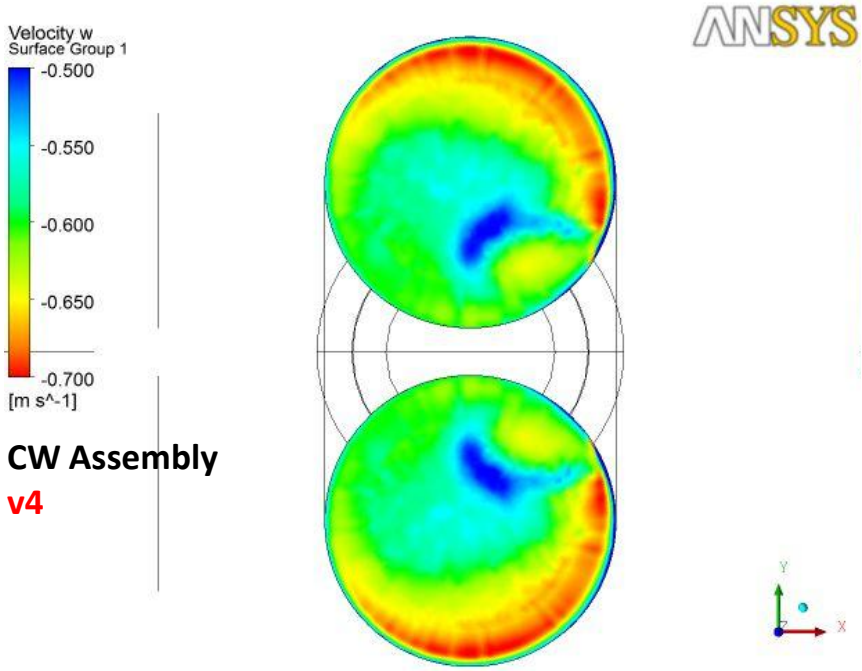
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CW Assembly
v2



CW Assembly
v3



CW Assembly
v4

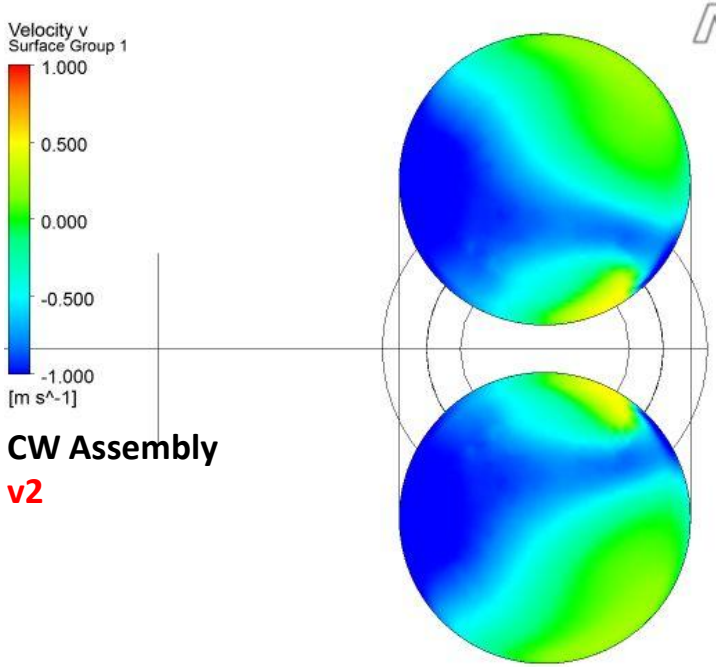
Velocity W, Cuts in Z 0.0 m above Entrance to HX, Narrowed Color Scale

(Normal to XY plane)

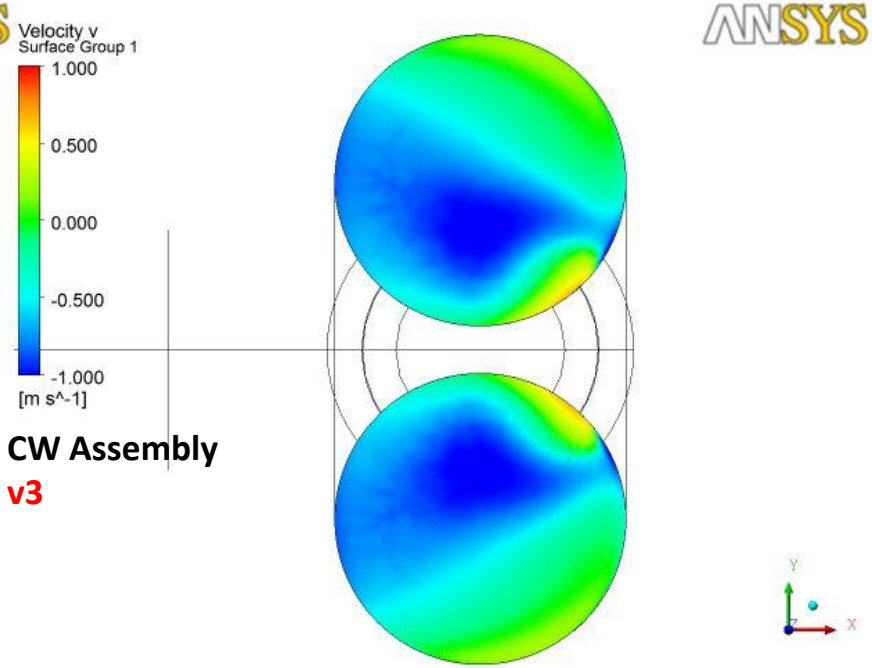
Note:

- Up is positive, down is negative

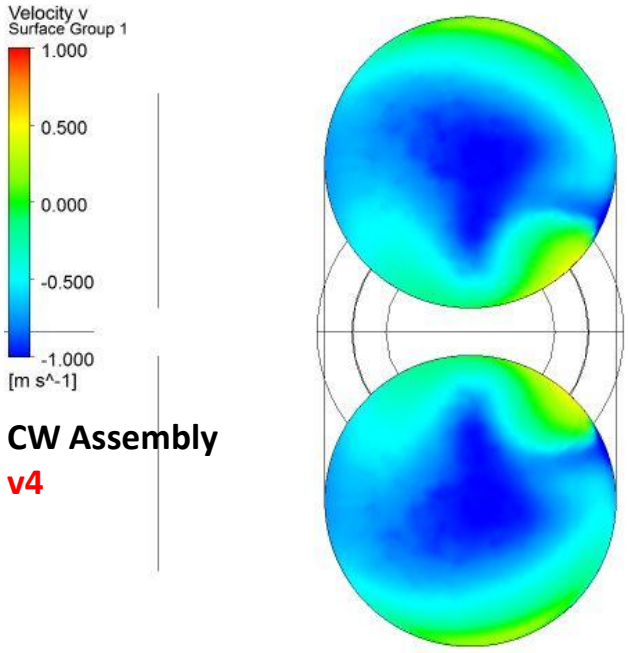
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CW Assembly
v2



CW Assembly
v3



CW Assembly
v4

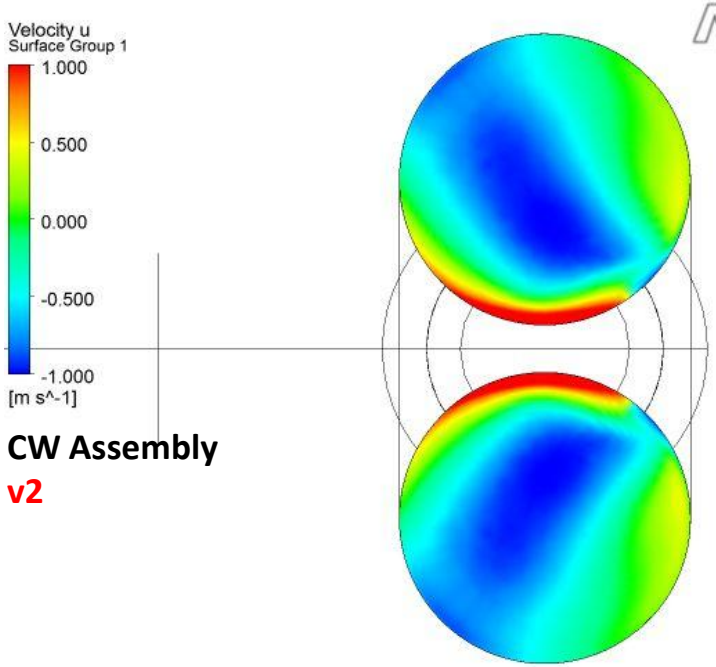
Velocity V, Cuts in Z 0.0 m above Entrance to HX

(Normal to XY plane)

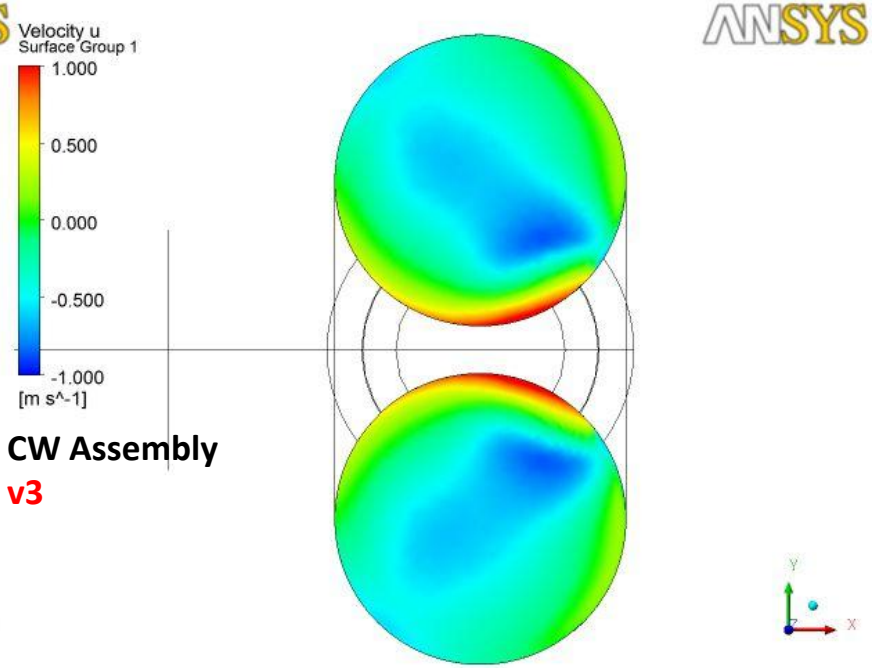
Note:

- Only half of the CW assembly was meshed (the half on the positive-Y, or top half looking at this image), and a symmetry plane defined in the solver to model the other half. The screenshots were created by selecting a mirror image to be shown in the post-processor. Thus, the mirrored (bottom) half for this image should be opposite in color, ranging from -1 m/s as red to +1 m/s as blue.

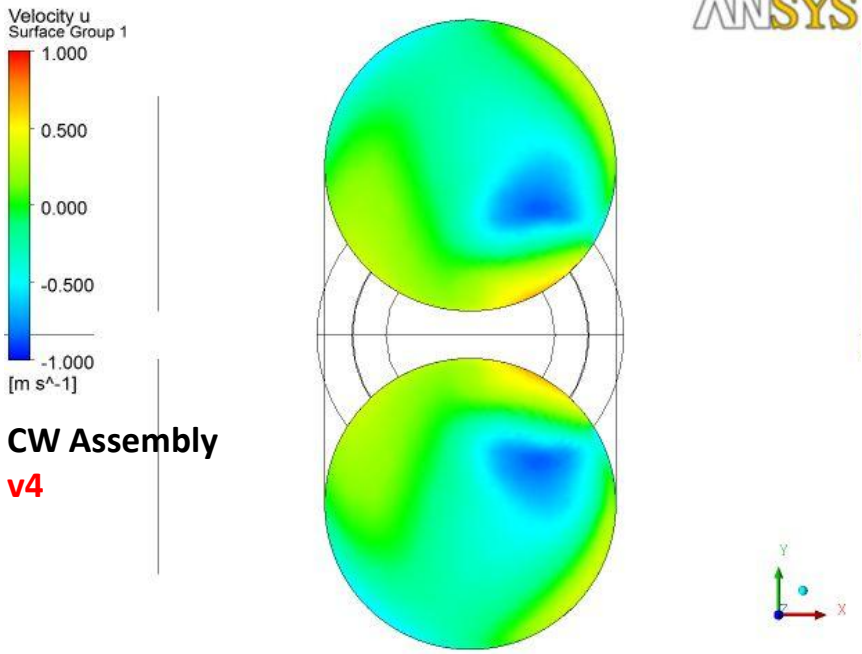
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CW Assembly
v2



CW Assembly
v3



CW Assembly
v4

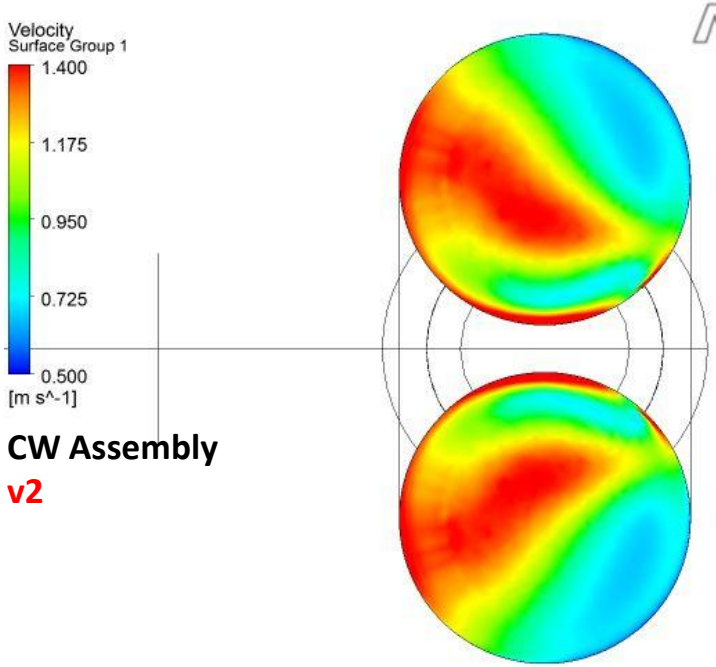
Velocity U, Cuts in Z 0.0 m above Entrance to HX

(Normal to XY plane)

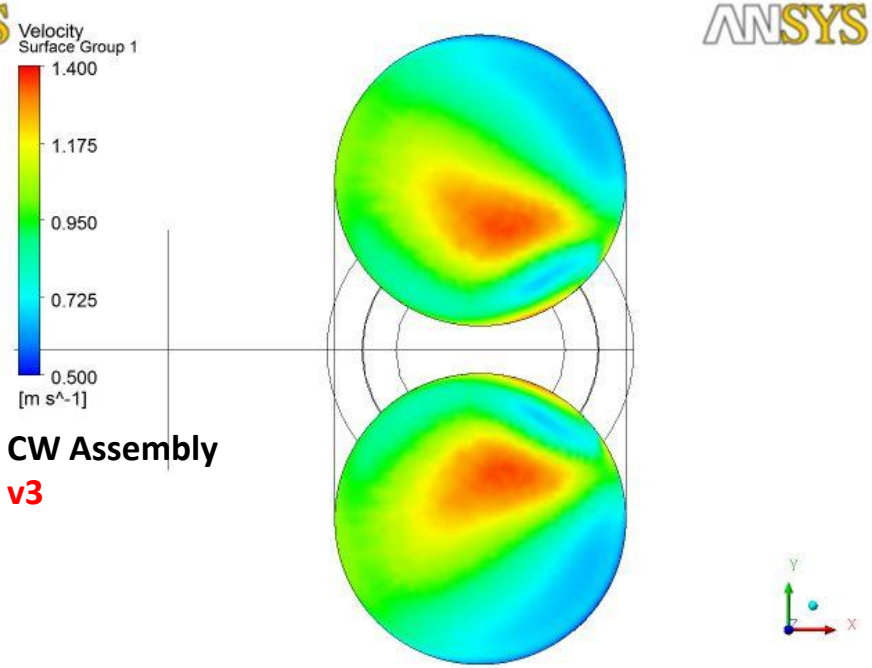
Note:

- Looking at these images, flow to the right is positive, and flow to the left is negative.

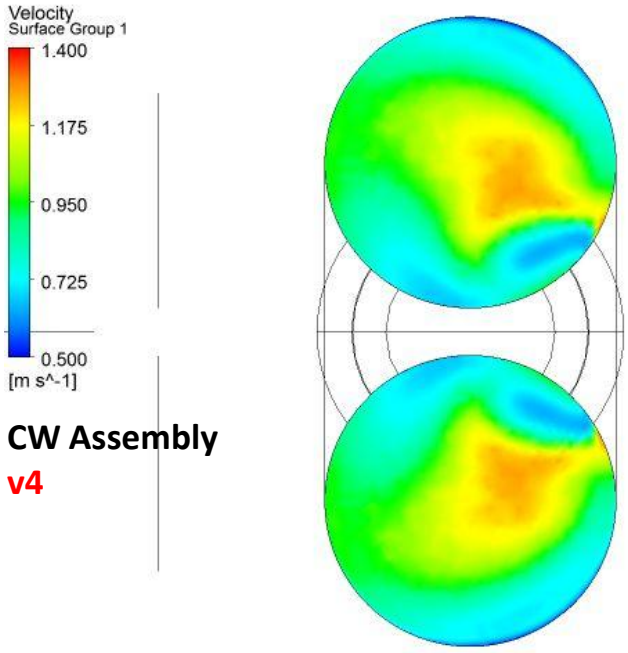
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CW Assembly
v2



CW Assembly
v3



CW Assembly
v4

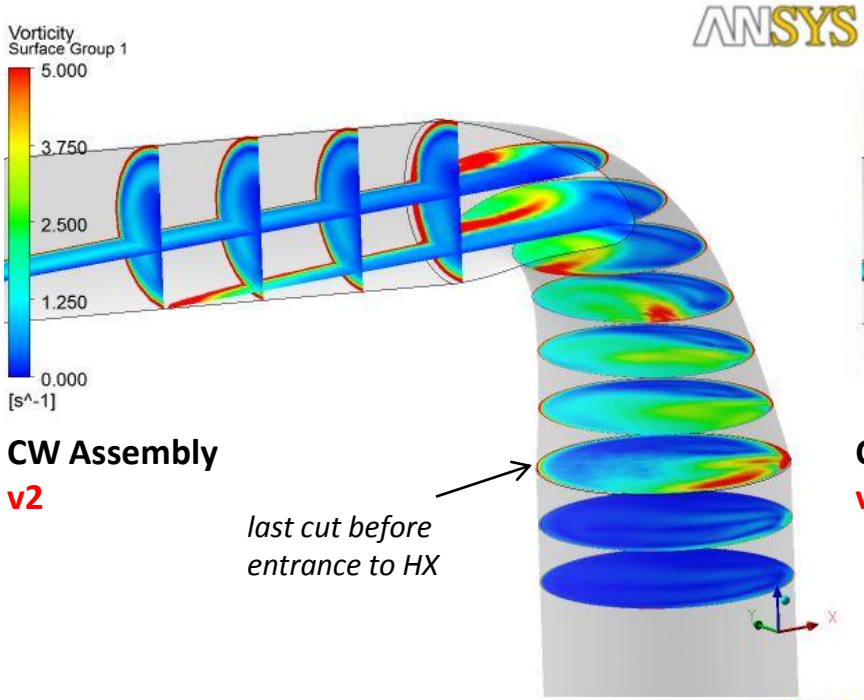
Velocity, Cuts in Z 0.0 m above Entrance to HX

(Normal to XY plane)

Observations:

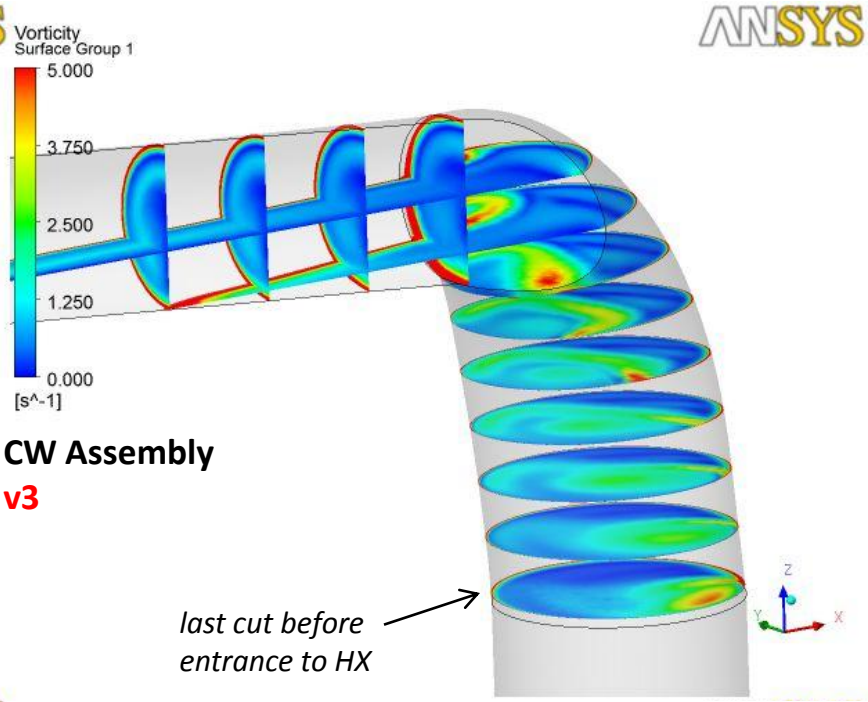
- Although flow is still not uniform at the entrance of the heat exchanger, uniformity seems to have improved slightly in CW assembly v3 and v4.

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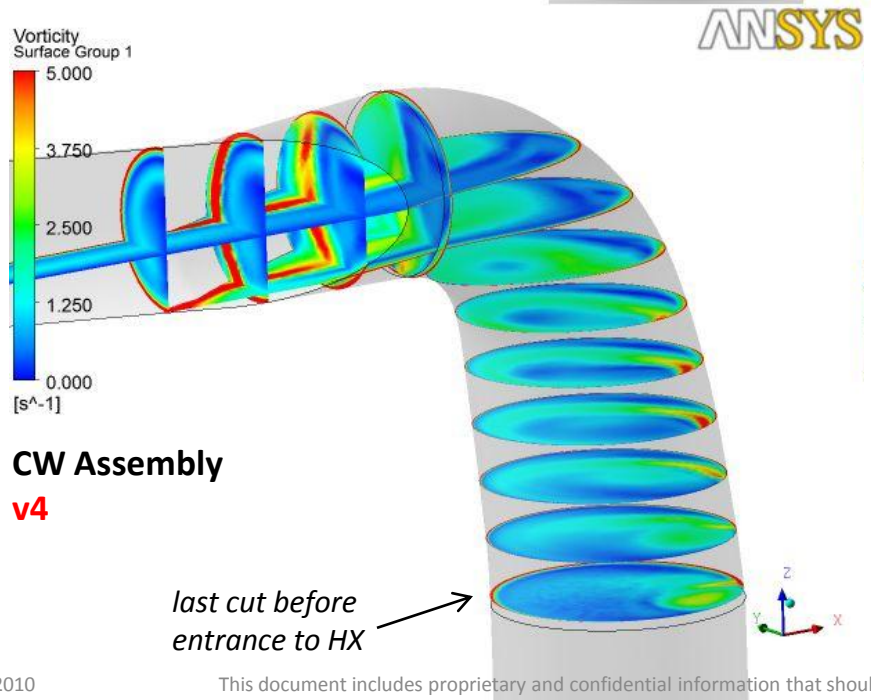
CW Assembly
v2

last cut before entrance to HX



CW Assembly
v3

last cut before entrance to HX



CW Assembly
v4

last cut before entrance to HX

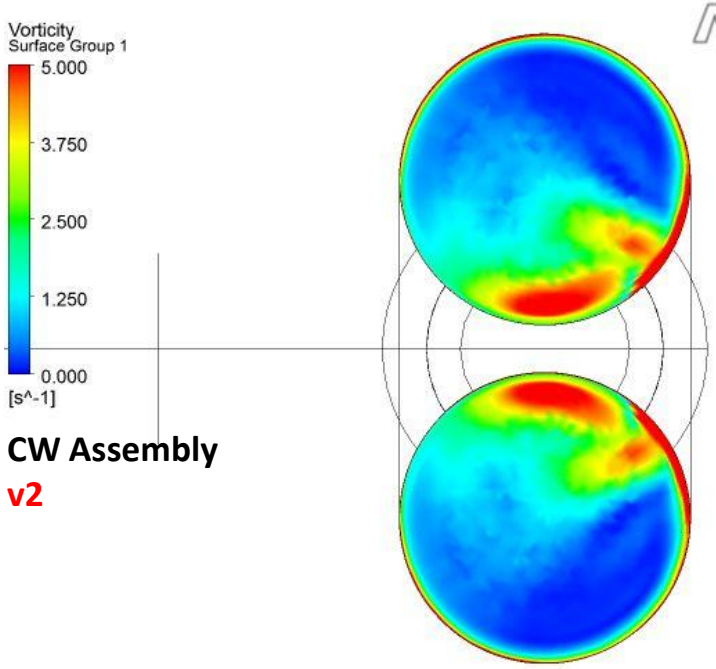
Vorticity, Cuts in X and Z

(Cuts in X spaced 2m apart, cuts in Z spaced 1m apart)

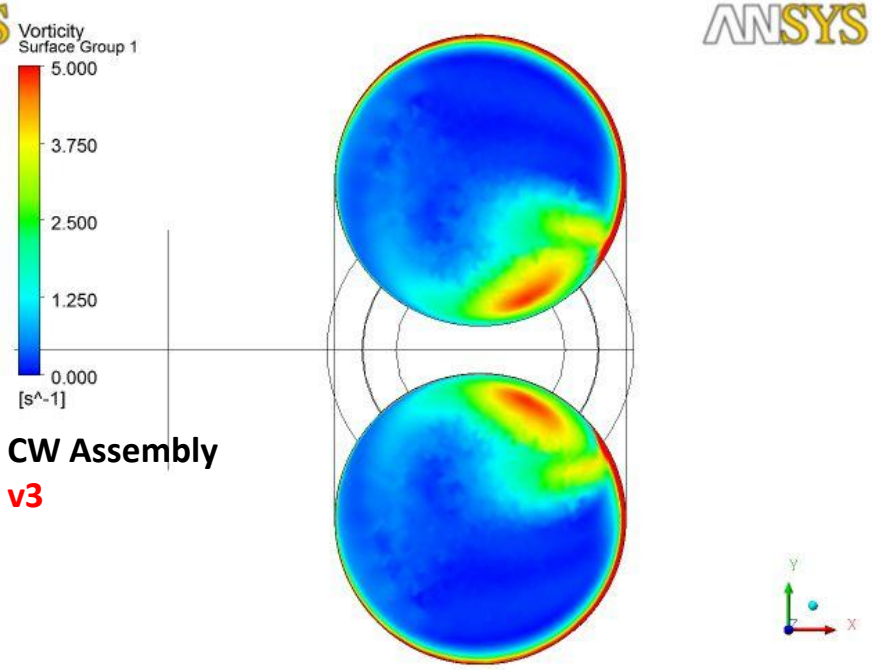
Notes and Observations:

- Vorticity is the curl of the velocity vector.
- Vorticity is reduced for CW assembly v3 and v4 compared to v2.

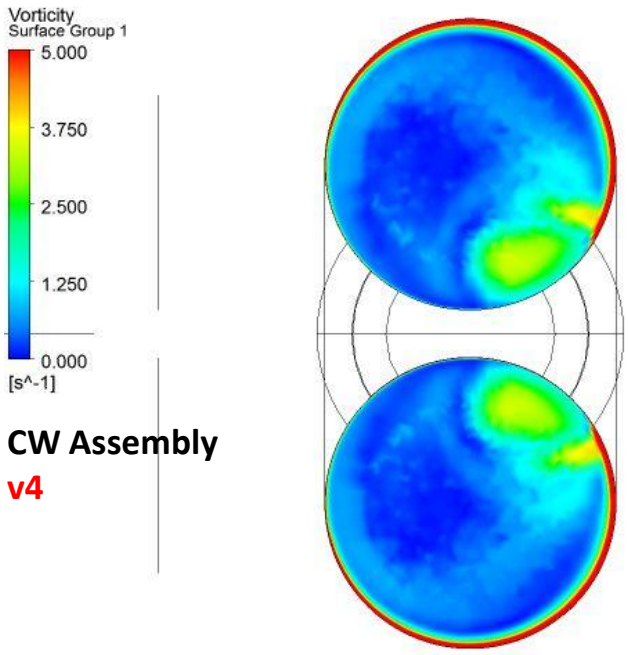
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CW Assembly
v2



CW Assembly
v3



CW Assembly
v4

Vorticity, Cuts in Z 0.0 m above Entrance to HX

(Normal to XY plane)

Notes and Observations:

- Compared to CW assembly v2, vorticity is reduced for v3, and further reduced for v4 at the entrance of the heat exchanger.

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NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-36
Power Delivery Supplemental Information
OTEC-2010-001

17 September 2010

Prepared for:

Naval Facilities Engineering Command
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Distribution Statement A: Approved for public release; distribution is unlimited

Appendix 3.3.3 Power Delivery Supplemental Information

This appendix contains the single-line diagram and physical layout of the OTEC electrical system for the pilot plant. Table A3.3.3-1 shows the high level power distribution of the generated power of the 5 MW system throughout the range of resource availability. The drawing set is labeled Figures 3.3.3-1 to 3.3.3-14. The complete drawing package represents the implementation of all requirements, trade studies, and design decisions related to the contract efforts. Finally, Table A3.3.3-2 and Figures A3.3.3-15 and -16 show the submarine cable analysis that took place during the contract to determine the best size for the cable.

Table: A3.3.3-1: Power Budget for the 5 MW OTEC Plant

5 MW Plant-max Output

OTEC Power Budget	Apparent (kVA)	Real (kW)	P.F.	% Gross Power
Generation	**10,677.23**	**8,827.95**	**0.83**	**-**
Internal Plant Losses	**2,483.01**	**2,228.61**	**0.90**	**25.24%**
- Seawater Pumps	1,972.22	1,775.00	0.90	**20.11%**
- Working Fluid Pumps	121.90	103.61	0.85	**1.17%**
- Auxilliary Systems	388.89	350.00	0.90	**3.96%**
Transmission Inefficiency	**244.23**	**239.34**	**0.98**	**2.71%**
Total Parasitic Loss	**2,727.23**	**2,467.95**	**0.90**	**27.96%**
Net Power Generation	**7,950.00**	**6,360.00**	**0.80**	**72.04%**

5 MW Plant-median Output

OTEC Power Budget	Apparent (kVA)	Real (kW)	P.F.	% Gross Power
Generation	**8,964.06**	**7,455.04**	**0.83**	**-**
Internal Plant Losses	**2,483.01**	**2,228.61**	**0.90**	**29.89%**
Transmission Inefficiency	**231.05**	**226.43**	**0.98**	**3.04%**
Total Parasitic Loss	**2,714.06**	**2,455.04**	**0.90**	**32.93%**
Net Power Generation	**6,250.00**	**5,000.00**	**0.80**	**67.07%**

5 MW Plant-min Output

OTEC Power Budget	Apparent (kVA)	Real (kW)	P.F.	% Gross Power
Generation	**6,691.07**	**5,625.77**	**0.84**	**-**
Internal Plant Losses	**2,483.01**	**2,228.61**	**0.90**	**39.61%**
Transmission Inefficiency	**170.57**	**167.16**	**0.98**	**2.97%**
Total Parasitic Loss	**2,653.57**	**2,395.77**	**0.90**	**42.59%**
Net Power Generation	**4,037.50**	**3,230.00**	**0.80**	**57.41%**

~~5 MW Cable~~ Not Used

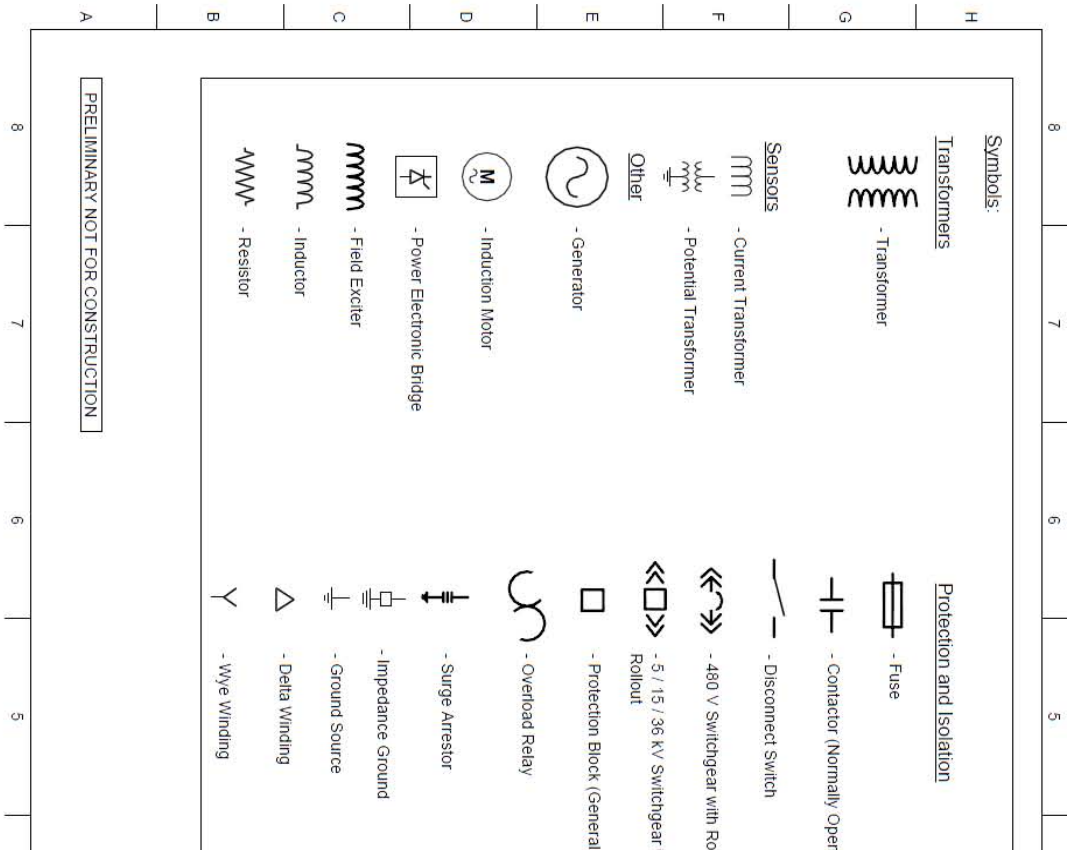
~~Transmission Calc~~	~~% Efficiency-min~~	~~% Efficiency-mean~~	~~% Efficiency-max~~
~~Platform Transformer~~	~~99.00%~~	~~99.00%~~	~~99.00%~~
~~Submarine Cable~~	~~98.00%~~	~~97.00%~~	~~96.60%~~
~~Onshore Transformer~~	~~99.00%~~	~~99.00%~~	~~99.00%~~
~~Effective Transmission~~	~~96.05%~~	~~95.07%~~	~~94.68%~~

10 MW Cable

Transmission Calc	% Efficiency-min	% Efficiency-mean	% Efficiency-max
Platform Transformer	99.00%	99.00%	99.00%
Submarine Cable	98.33%	97.61%	97.01%
Onshore Transformer	99.00%	99.00%	99.00%
Effective Transmission	96.37%	95.67%	95.08%

~1/2% efficiency improvement with larger cable

Ammonia Pump Worksheet	echanical Power (H	Efficiency (est)	lectric Power (kW)
Pump	125	90%	103.61



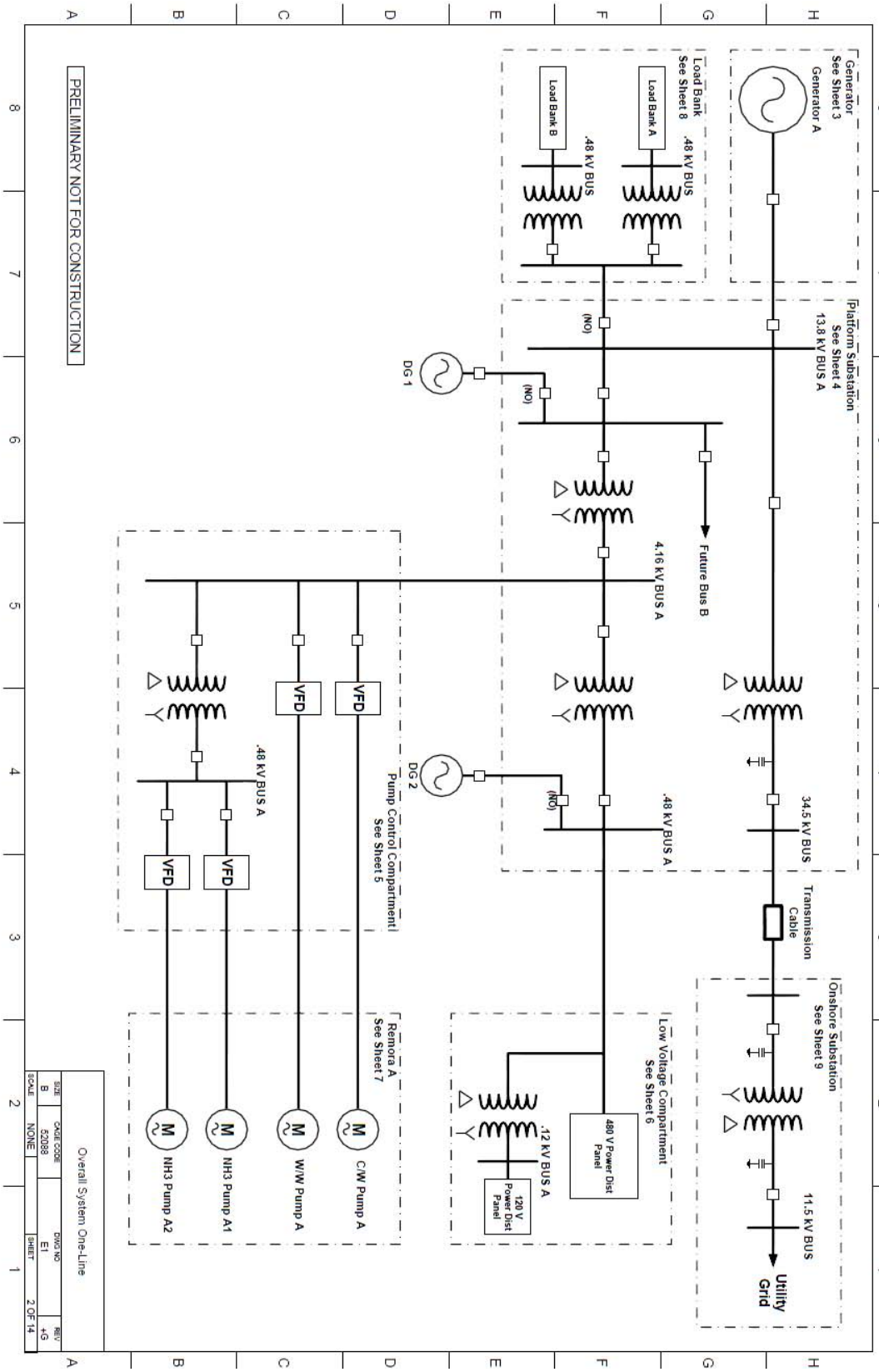


Figure A3.3.3-2: One-Line System Summary

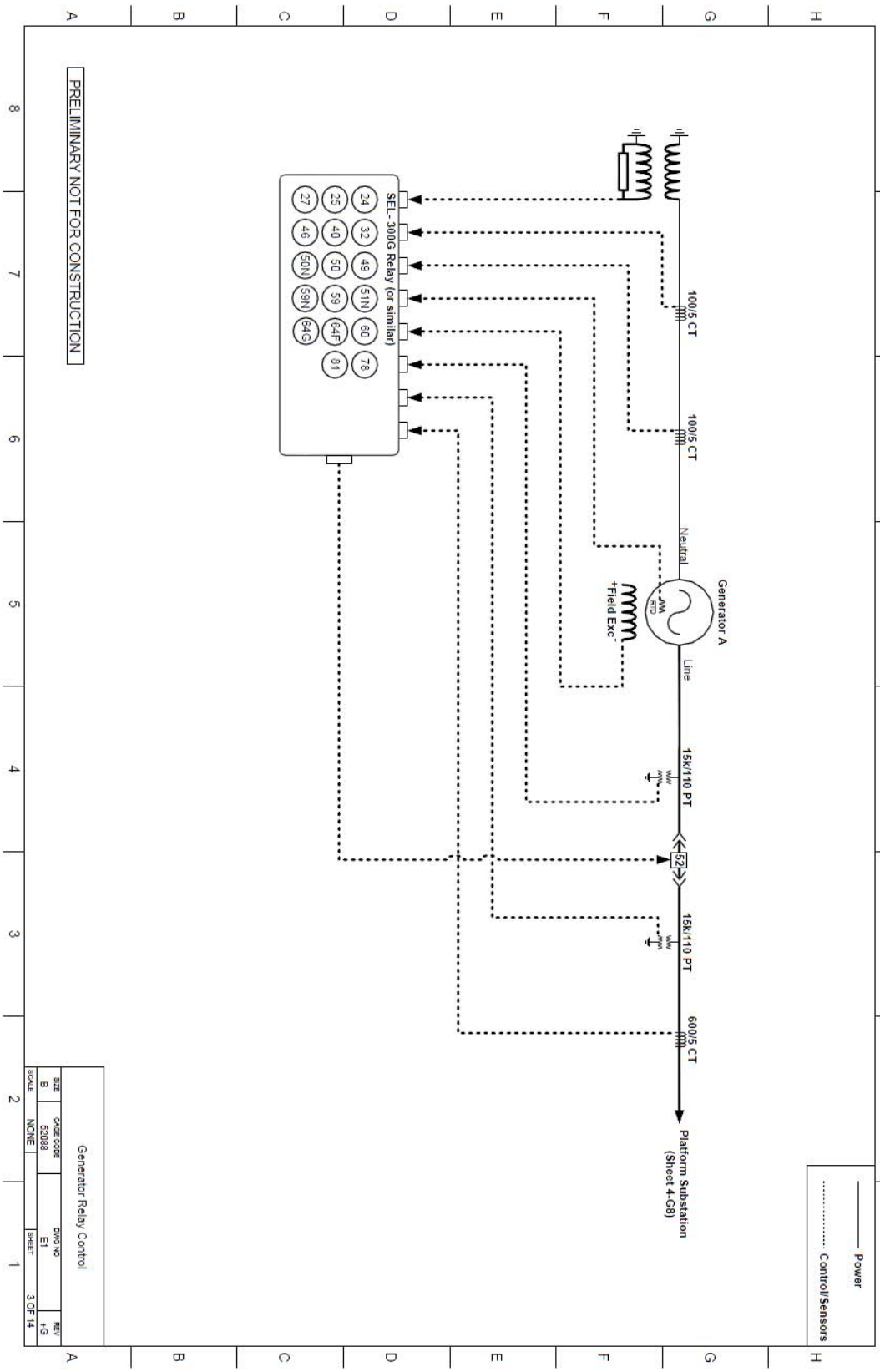


Figure A3.3.3-3: One-Line Generator Relay Control

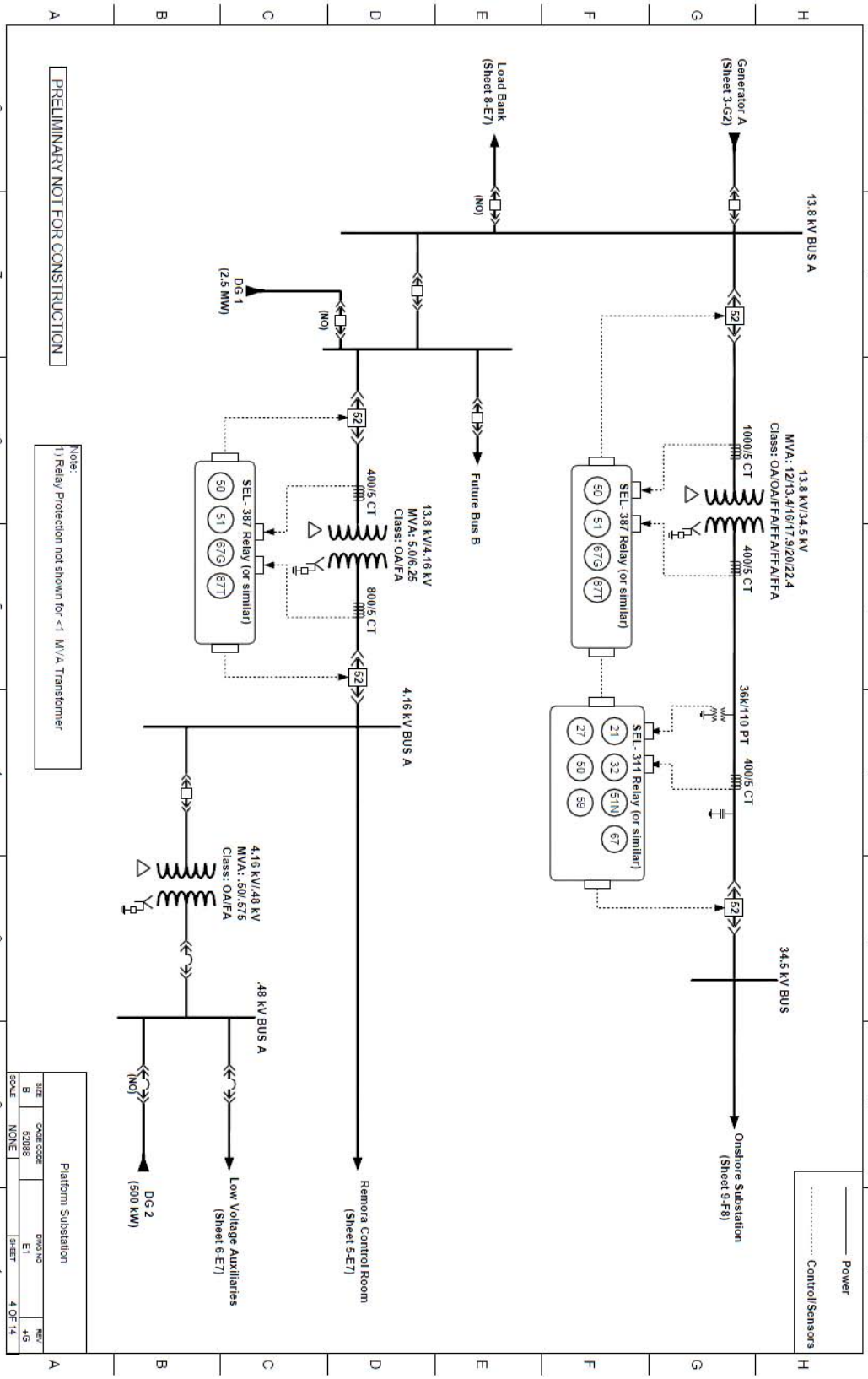


Figure A3.3.3-4: One-Line Platform Substation

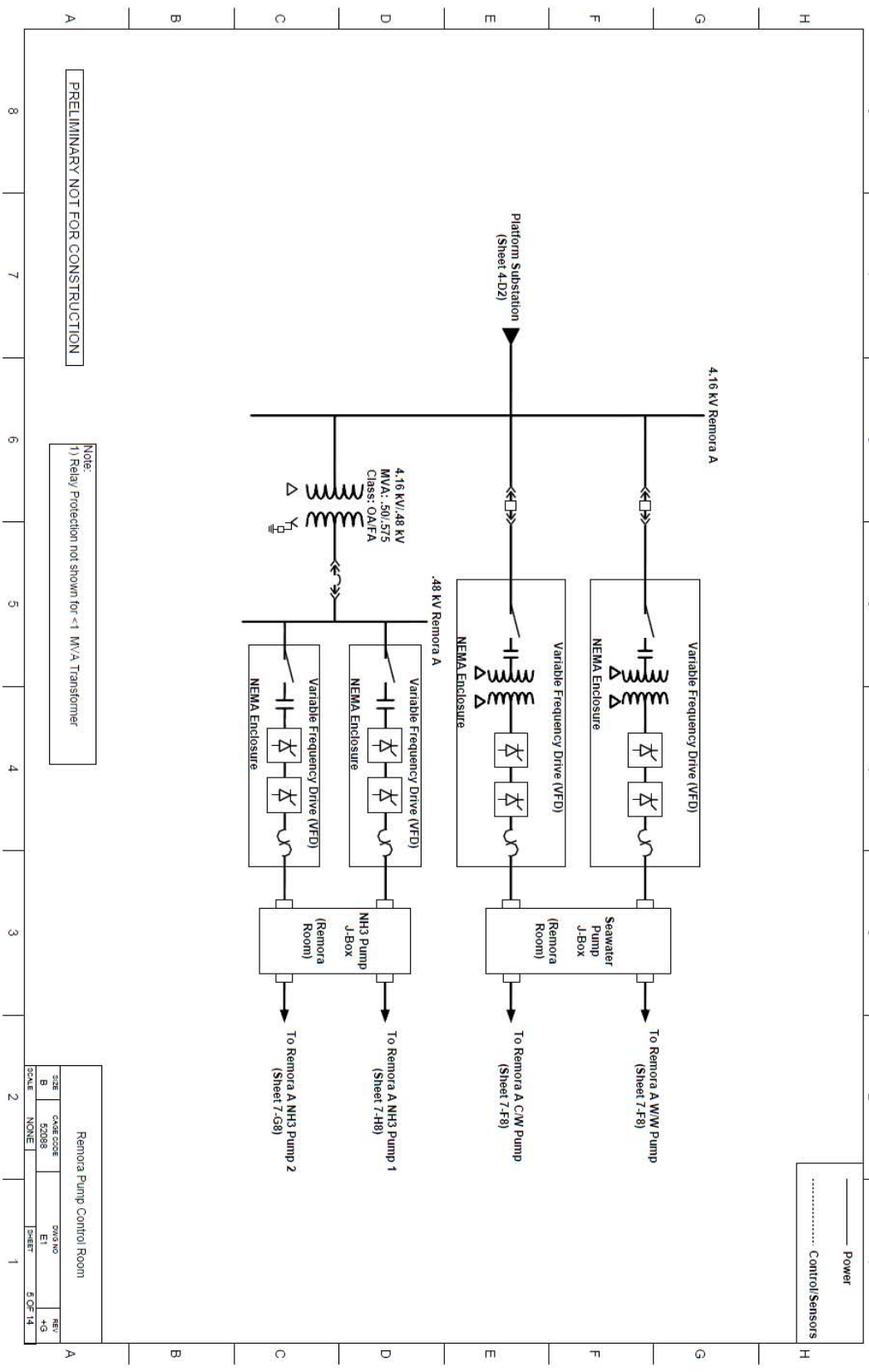


Figure A3.3.3-5: One-Line Remora Pump Control Room

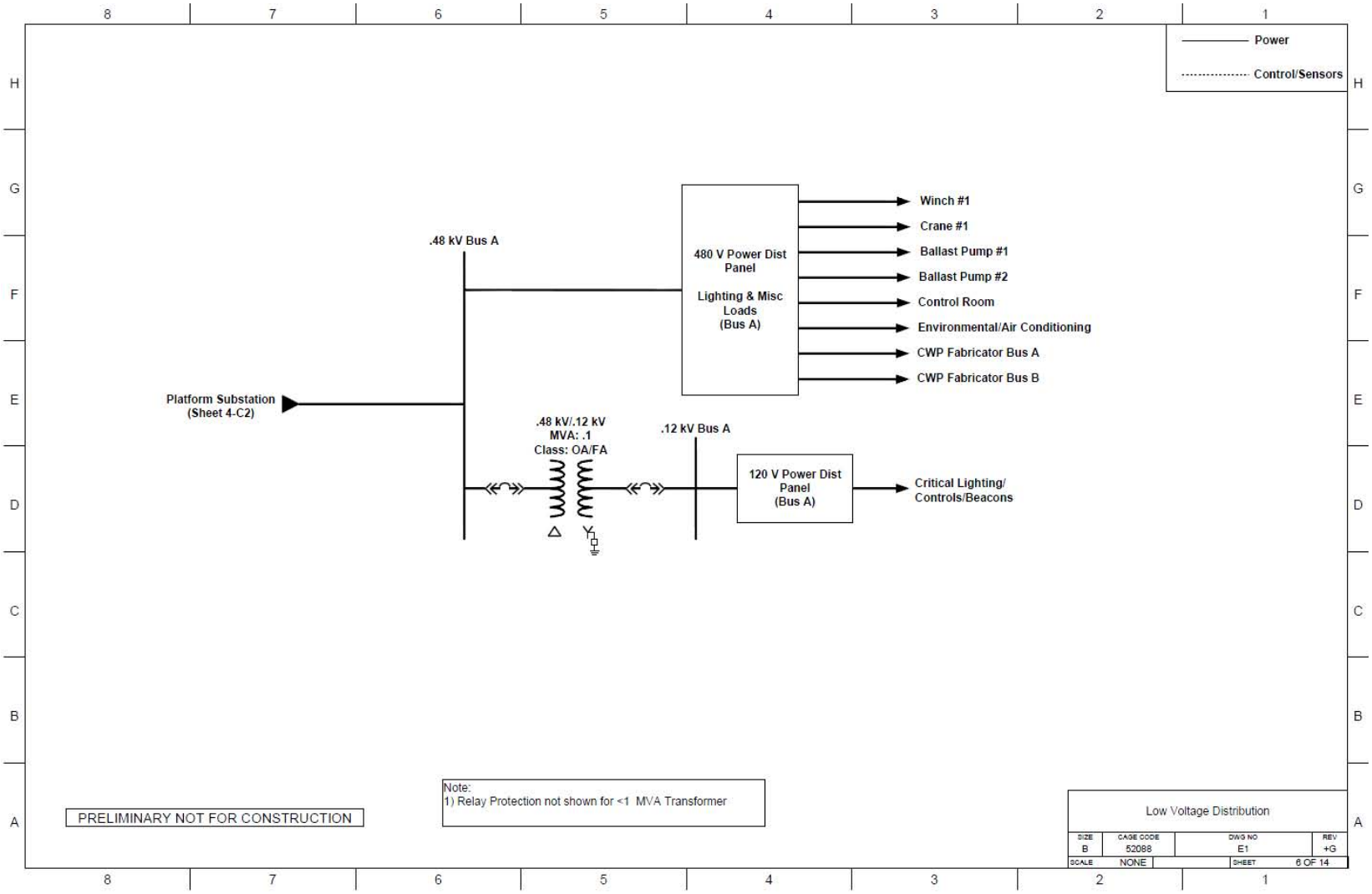


Figure A3.3.3-6: One-Line Low Voltage Distribution

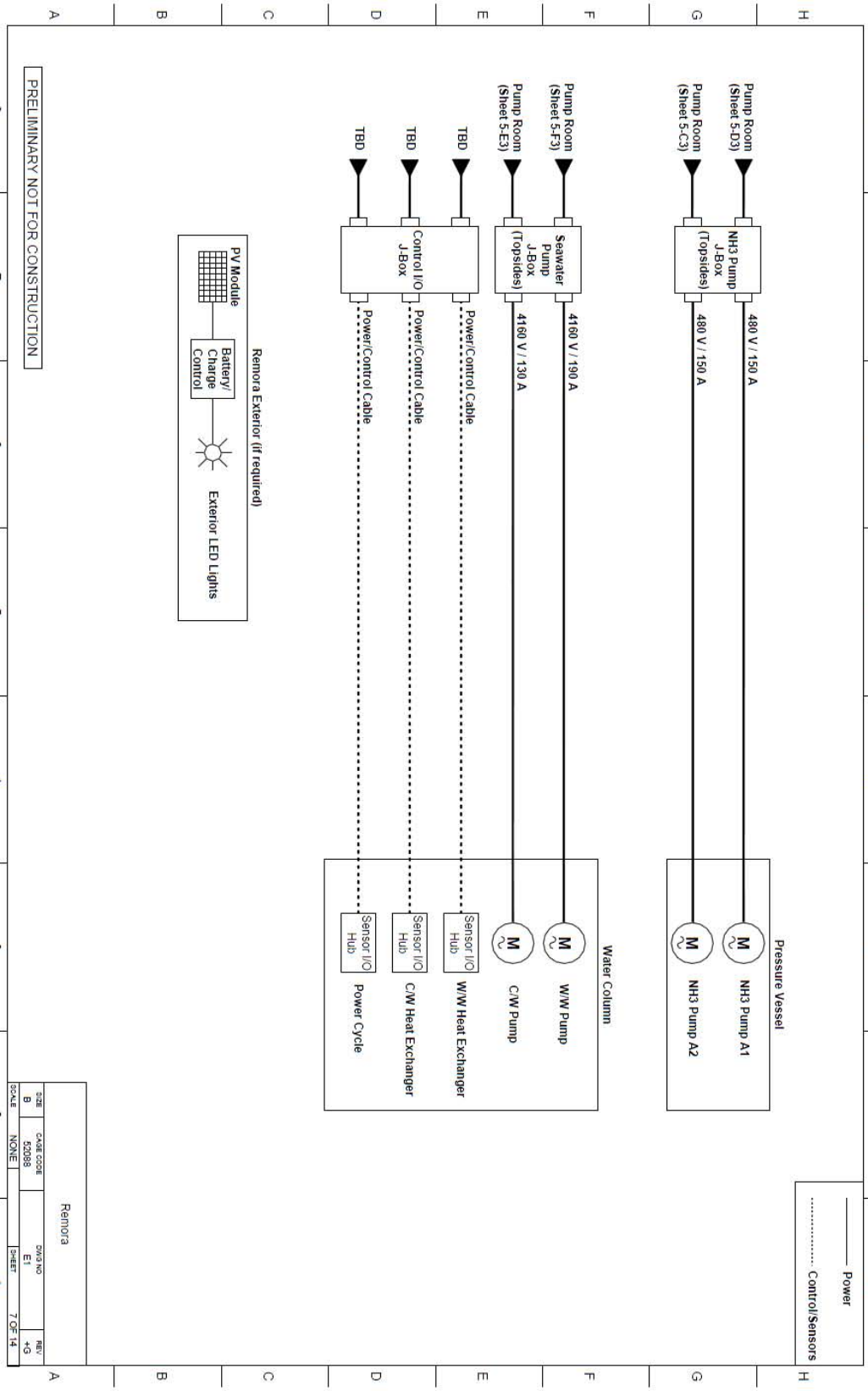


Figure A3.3.3-7: One-Line Remora

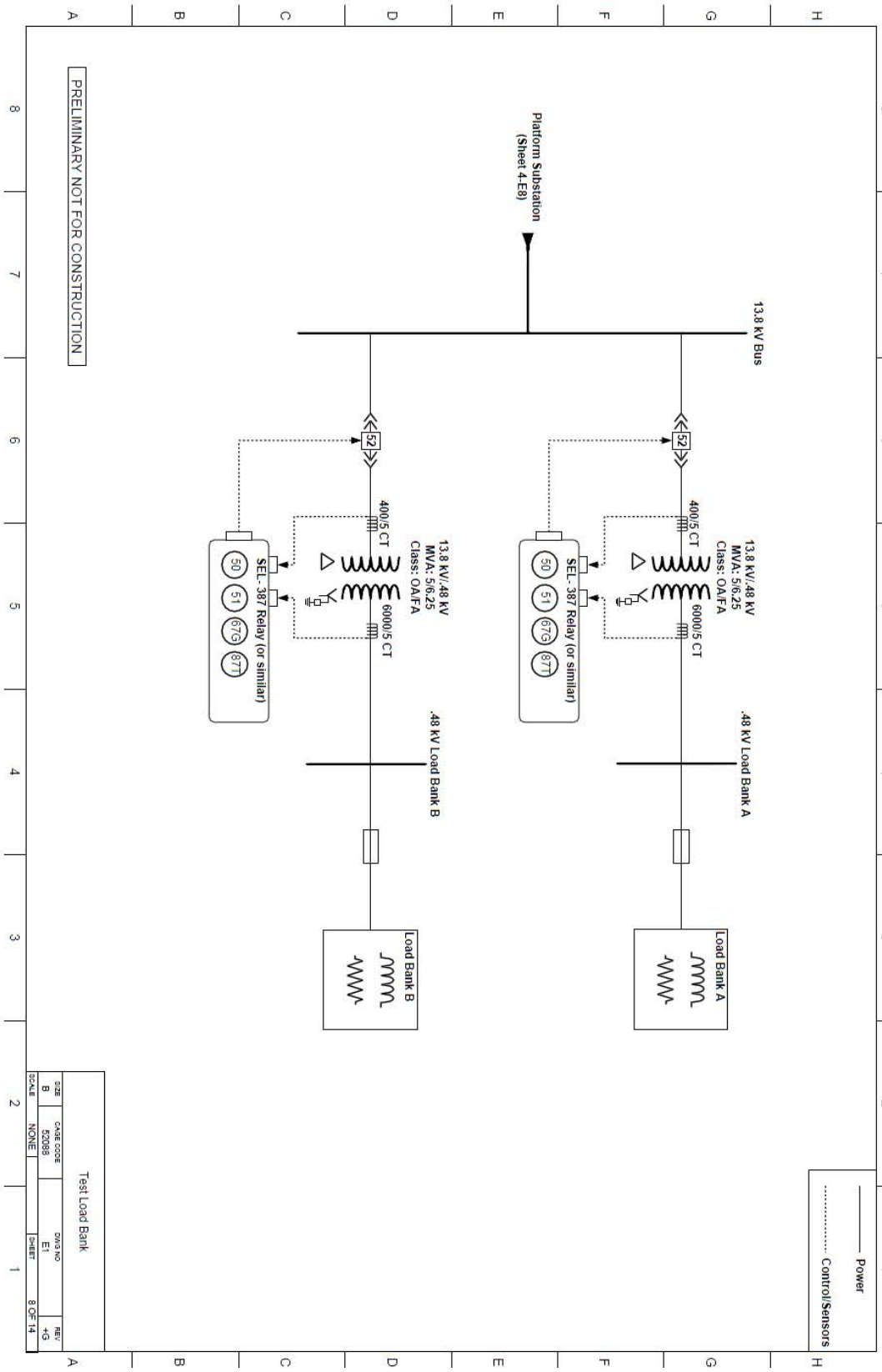


Figure A3.3.3-8: One-Line Test Load Bank

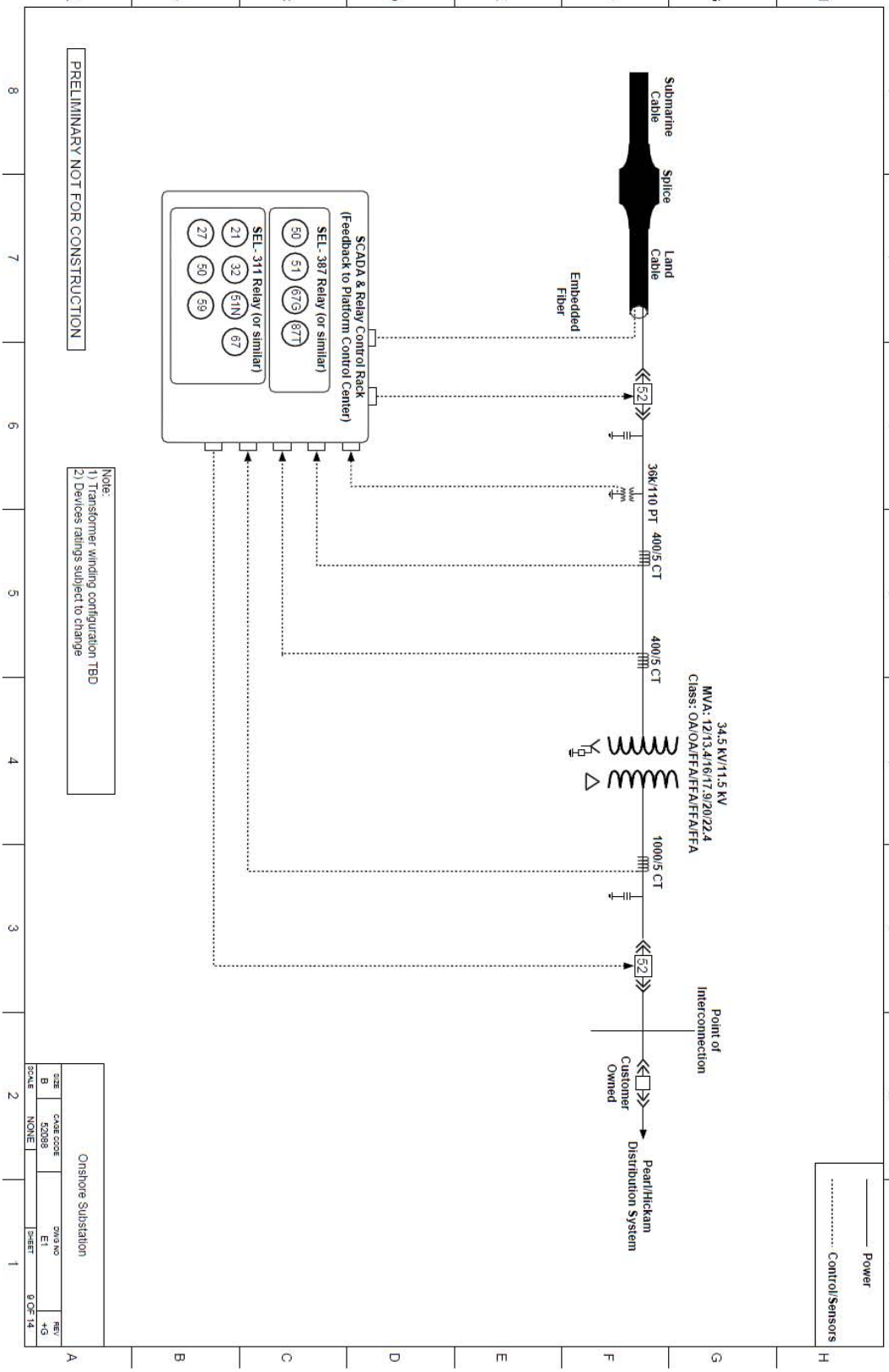


Figure A3.3.3-9: One-Line Onshore Substation

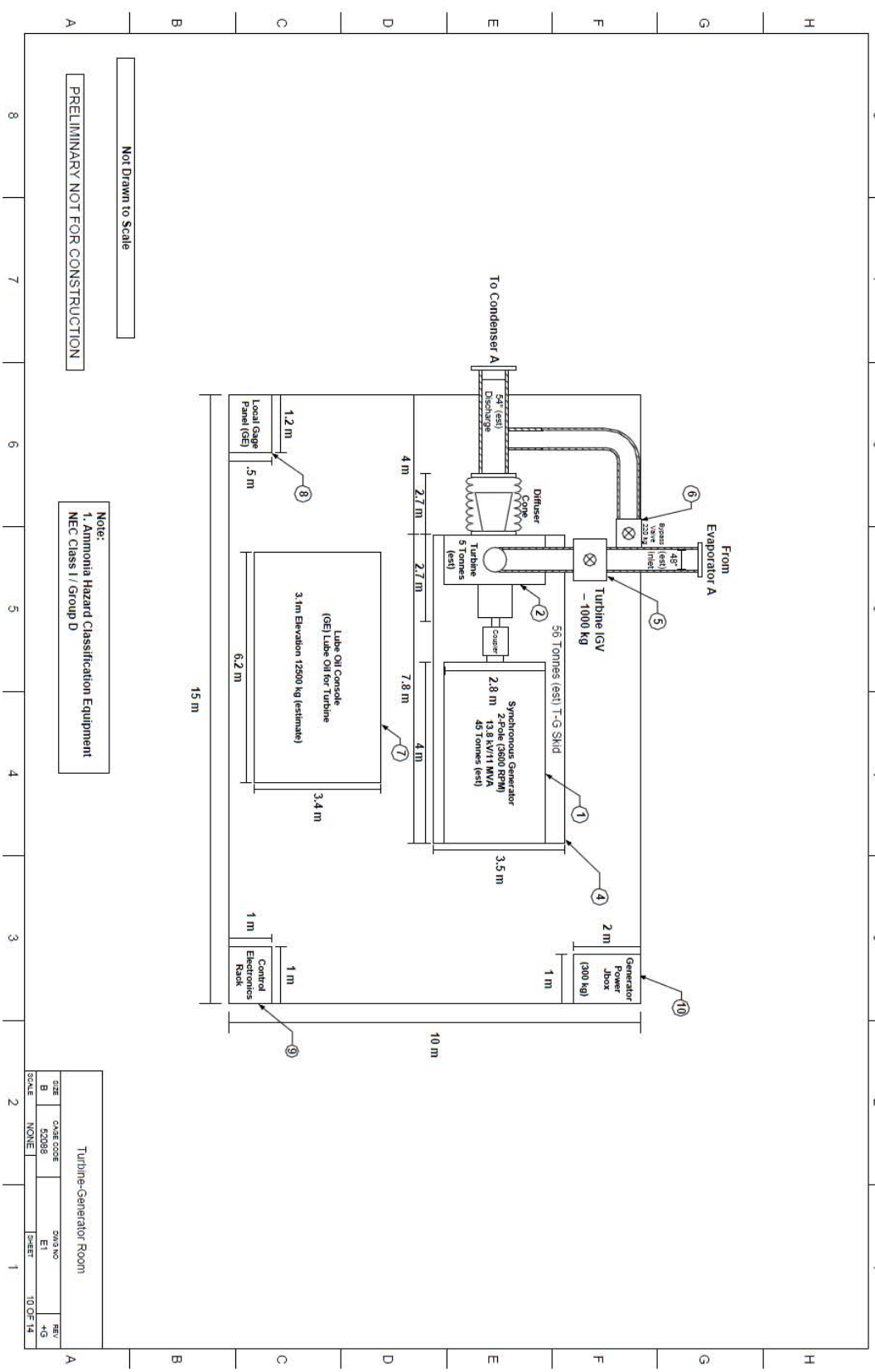


Figure A3.3.3-10: Physical Layout Turbine-Generator Room

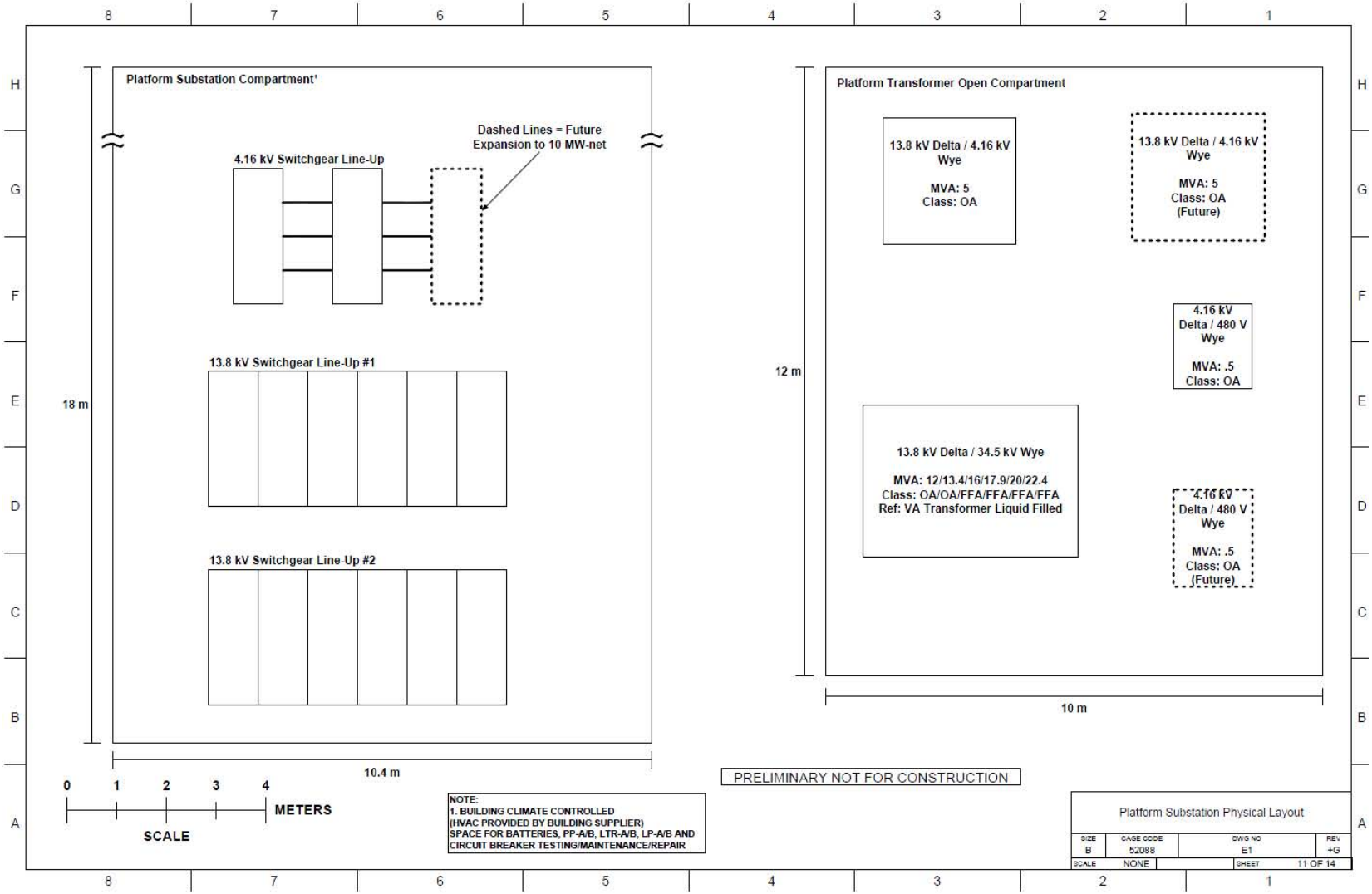


Figure A3.3.3-11: Physical Layout Platform Substation

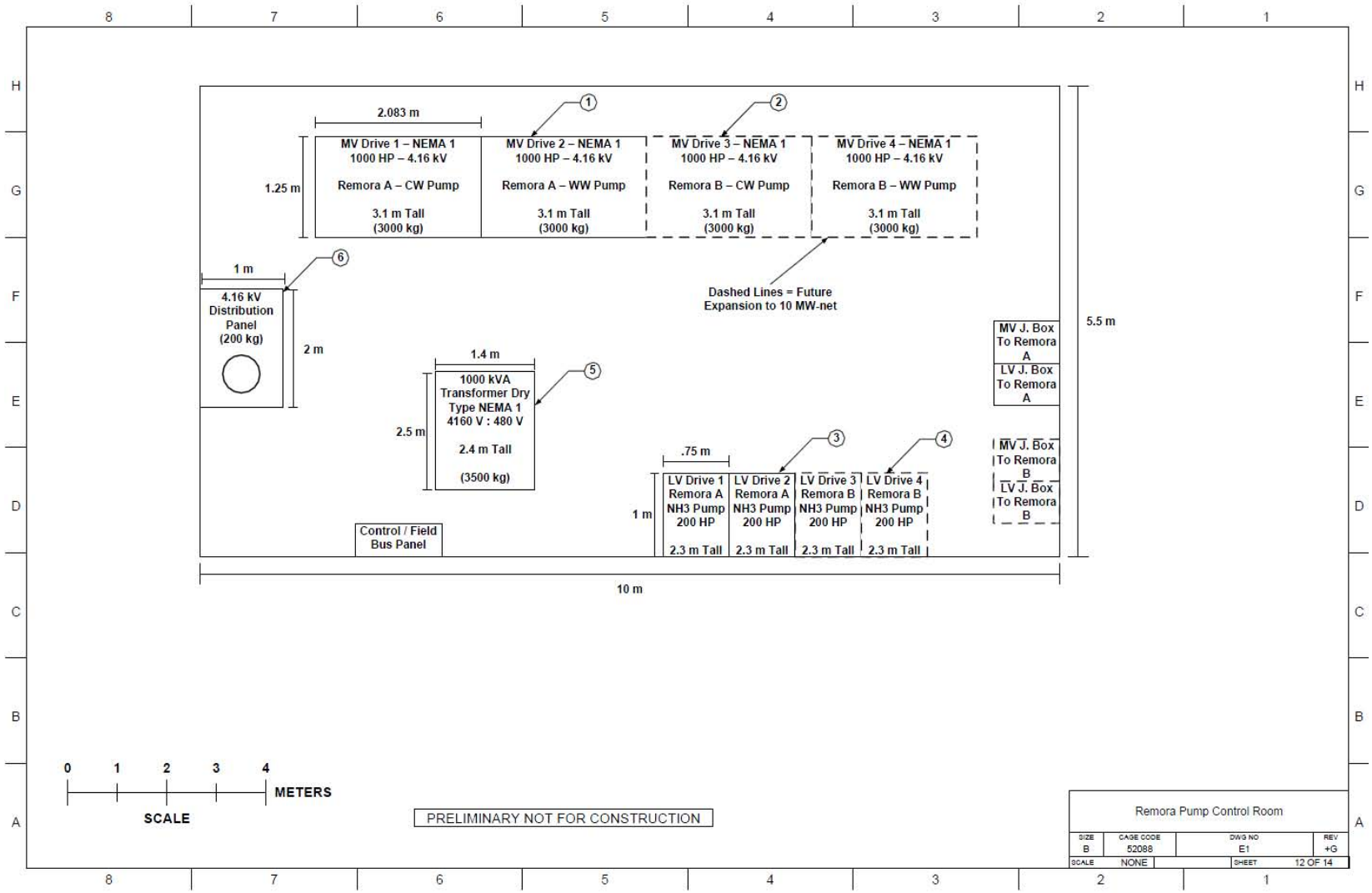


Figure A3.3.3-12: Physical Layout Remora Pump Control Room

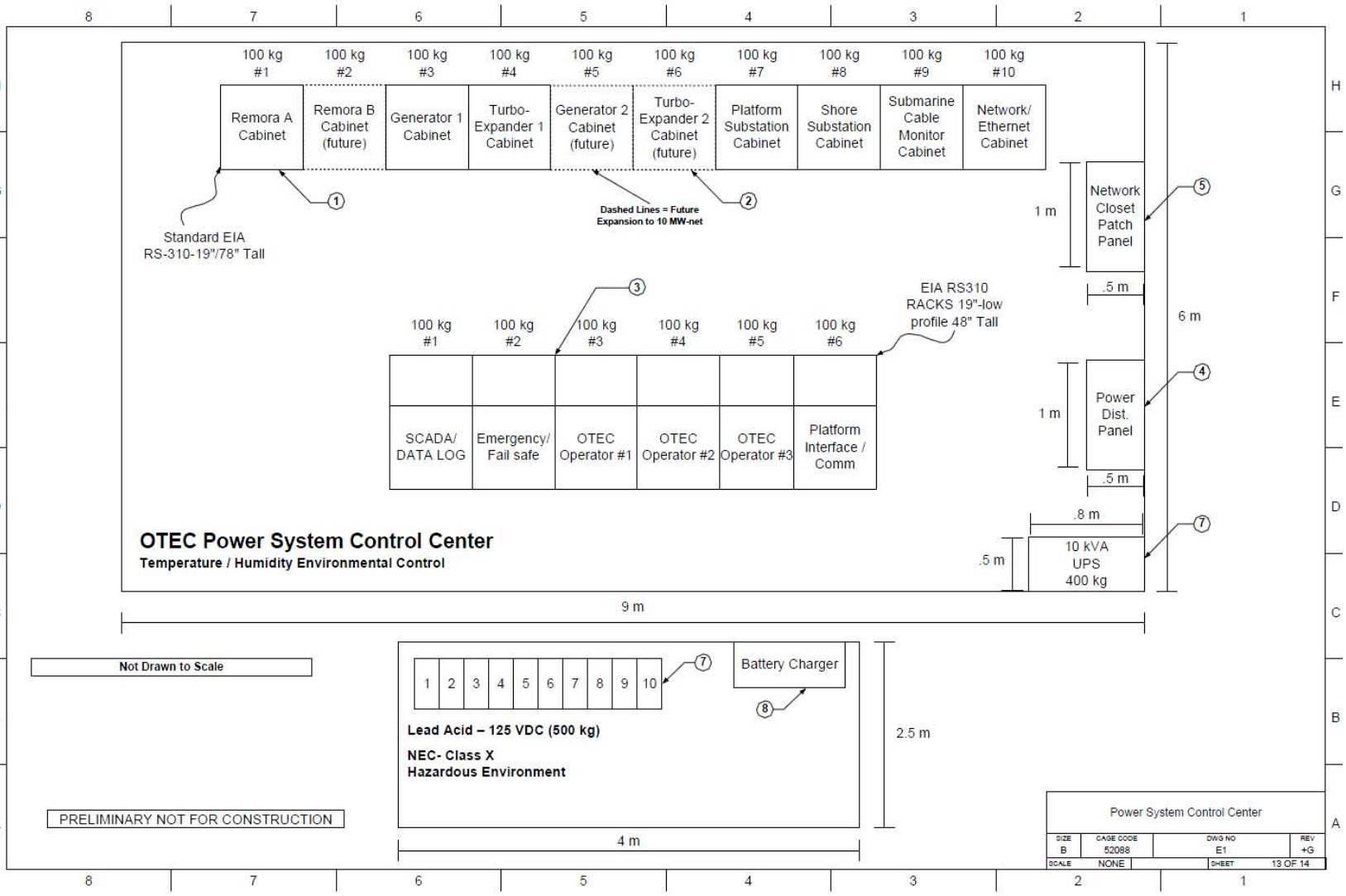


Figure A3.3.3-13: Physical Layout Power System Control Center

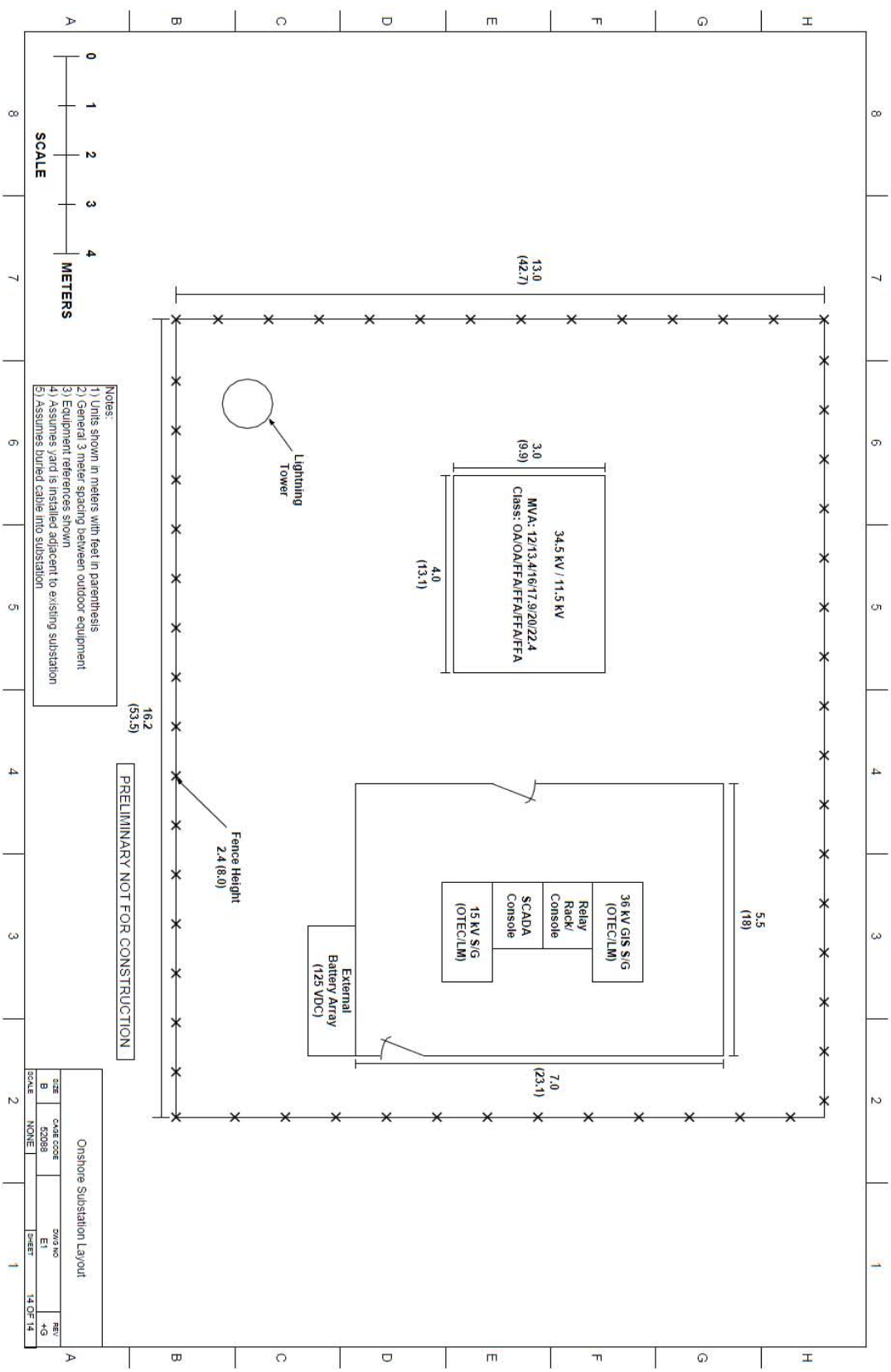


Figure A3.3.3-14: Physical Layout Onshore Substation

Table A3.3.3-2: Submarine Cable 33 kV vs. 60 kV Analysis

33 kV @ 6 MW

Cable Length (km)	Efficiency (%)	Voltage Regulation (%)	Sending Voltage (kV)	Receiving Voltage (kV)	Sending Power (MW)	Receiving Power (MW)
5	99.52	0.58	33.19	33	6.03	6
10	99.06	1.15	33.38	33	6.06	6
15	98.62	1.69	33.56	33	6.08	6
20	98.21	2.22	33.73	33	6.11	6
25	97.69	2.73	33.9	33	6.14	6
30	97.25	3.22	34.06	33	6.17	6
35	96.83	3.69	34.22	33	6.2	6

33 kV @ 12 MW

Cable Length (km)	Efficiency (%)	Voltage Regulation (%)	Sending Voltage (kV)	Receiving Voltage (kV)	Sending Power (MW)	Receiving Power (MW)
5	99.03	1.18	33.39	33	12.12	12
10	98.09	2.33	33.77	33	12.23	12
15	97.19	3.47	34.15	33	12.35	12
20	96.33	4.6	34.52	33	12.46	12
25	95.5	5.7	34.88	33	12.57	12
30	94.7	6.79	35.24	33	12.67	12
35	93.81	7.86	35.59	33	12.79	12

60 kV @ 6 MW

Cable Length (km)	Efficiency (%)	Voltage Regulation (%)	Sending Voltage (kV)	Receiving Voltage (kV)	Sending Power (MW)	Receiving Power (MW)
5	99.82	0.21	60.13	60	6.01	6
10	99.65	0.4	60.24	60	6.02	6
15	99.38	0.58	60.35	60	6.04	6
20	99.14	0.73	60.44	60	6.05	6
25	98.89	0.87	60.52	60	6.07	6
30	98.61	0.99	60.6	60	6.08	6
35	98.3	1.1	60.66	60	6.1	6

60 kV @ 12 MW

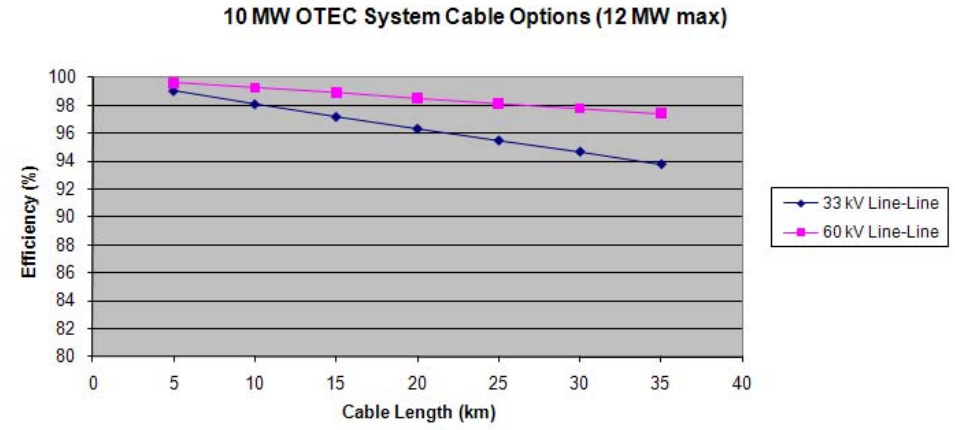
Cable Length (km)	Efficiency (%)	Voltage Regulation (%)	Sending Voltage (kV)	Receiving Voltage (kV)	Sending Power (MW)	Receiving Power (MW)
5	99.62	0.43	60.26	60	12.05	12
10	99.27	0.84	60.5	60	12.09	12
15	98.93	1.23	60.74	60	12.13	12
20	98.51	1.61	60.96	60	12.18	12
25	98.15	1.96	61.18	60	12.23	12
30	97.8	2.31	61.38	60	12.27	12
35	97.44	2.63	61.58	60	12.32	12

Cable Parameters (33 kV)

Conductor Diameter (mm)	Insulator Outer Diameter (mm)	Power Factor	Derating Factor*
12.8	30.4	0.85	0.893

Cable Parameters (60 kV)

Conductor Diameter (mm)	Insulator Outer Diameter (mm)	Power Factor	Derating Factor*
11.2	30.8	0.85	0.893



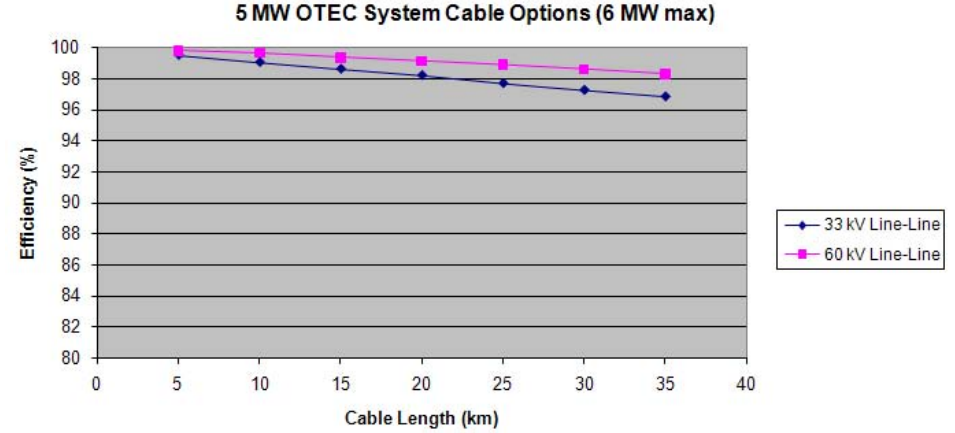


Figure A3.3.3-15: Efficiency vs. Length for 33 kV and 60 kV Submarine Cable

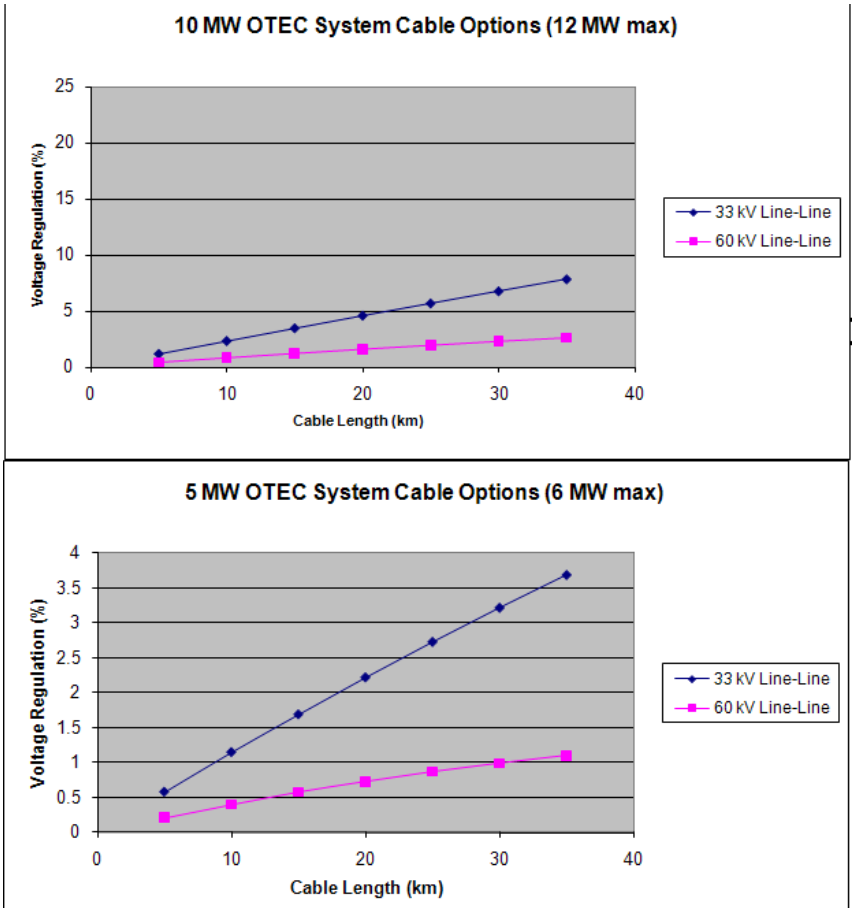


Figure A3.3.3-16: Voltage Regulation vs. Length for 33 kV and 60 kV Submarine Cable

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-37
OTEC Grid ICD Draft Final
OTEC-2010-001

17 September 2010

Prepared for:

Naval Facilities Engineering Command
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OTEC PILOT PLANT TO PEARL HARBOR/HICKAM AIRFIELD DISTRIBUTION NETWORK INTERFACE CONTROL DOCUMENT

FOR THE

NAVFAC OTEC PILOT PLANT

9/17/2010

Page Date: 17 SEP 2010

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TBD/TBR LISTING

Paragraph	Page Number	TBD/TBR	Description
-	1	TBD	Reproduction Information
1	12	TBD	Routing of submarine cable onshore
3	17	TBD	Data communications definition between the interface
2	18	TBR	Current rating for bus between interface
2	19	TBR	Rated battery capacity for onshore substation array
5	24	TBR	Thermal resistivity and HDD for submarine cable
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1	26	TBR	Onshore switchgear type
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Section 1 Scope

1.1 Identification

This Interface Control Document (ICD) establishes the electrical interface requirements between the OTEC Pilot Plant System and the Pearl Harbor/Hickam Airfield Distribution System on Oahu, Hawaii. For the purpose of this document, the Pearl Harbor/Hickam Airfield Distribution System will be referred to as the "customer" in all following sections. The ICD includes the systems top level requirements of the electrical connection to the grid on shore (e.g. voltage & frequency regulation), the protection of the independent subsystems (e.g. breaker coordination), the land-use (e.g. onshore-substation footprint), and the communications (e.g. protocols). Assumptions regarding the interface are highlighted accordingly throughout the document as TBD/TBR.

The OTEC Power Plant will deliver power directly to the customer distribution network. Power will be generated on the OTEC floating platform and delivered to shore via a submarine power cable. The average net-power delivered to the customer from the OTEC pilot plant will be 5 megawatts. The ICD describes how the interface is established, maintained, and regulated between the OTEC plant and customer. Figure 1.1 shows a block diagram of the OTEC power plant.

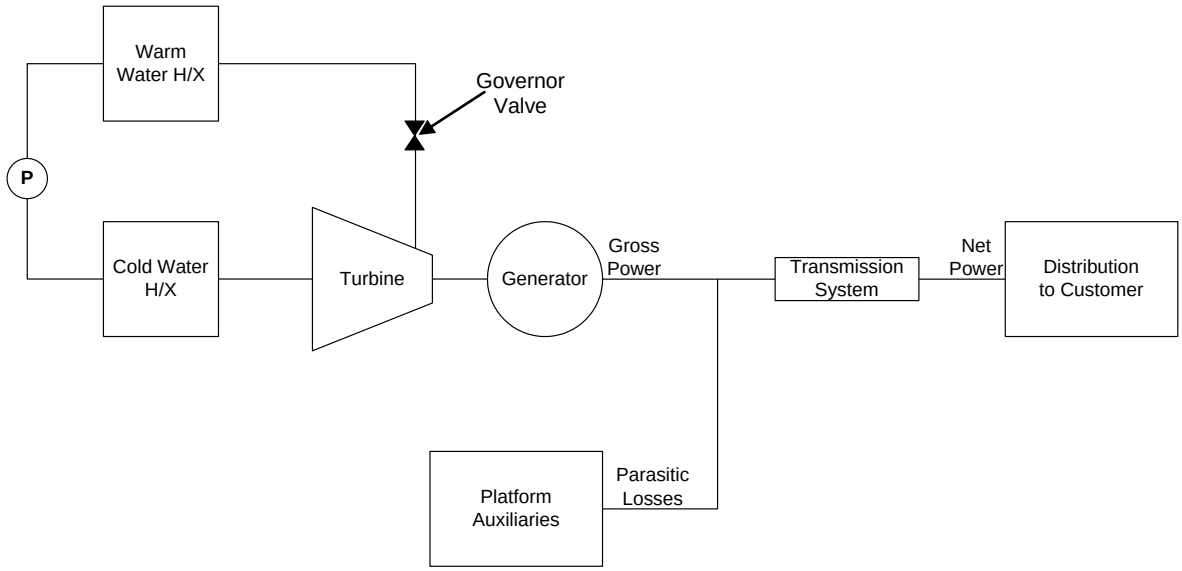


Figure 1.1: OTEC Pilot Plant block diagram

1.2 Document organization

This ICD is organized into 4 sections; scope, reference documents, requirements, and verification. The section titled "scope" lists the boundaries of the ICD (i.e. which components

make up the interface). The section titled “reference documents” contains information on the main documents and industry standards supporting the ICD. The “requirements” section addresses the customer specifications, environmental, and regulating parameters needed to define operational parameters for the plant. The “verification” section defines the process of commissioning the OTEC pilot plant; in particular the onshore substation and point of interconnect. The appendices contain relevant data for the system design.

1.3 Limitations and restrictions

The ICD encompasses the elements of the OTEC system relevant to the interface with the customer utility. This includes the following items:

1. Turbine
2. Electrical Generator
3. Submarine Power Cable
4. On-shore Substation
5. Protection System (as it relates to the customer interface)
6. Communication System (as it relates to the customer interface)

Elements of the OTEC power plant that are not part of the ICD include the following items:

1. Platform Station keeping subsystem
2. Cold and warm water subsystems
3. Ammonia Cycle (excluding turbine-governor)
4. Platform ancillary equipment (e.g. cranes, lighting, crew accommodation)

1.3.I Parameters for Interconnection Interface

The interface includes data exchanges for fault prevention and maintenance including electrical power flow parameters and communications.. The electrical parameters include voltage, frequency and current. In addition to electrical power flow monitoring, the protection equipment must also be specified and coordinated through the interface. The protection equipment includes breakers and protective relays to protect the OTEC plant and customer from fault events. Finally, the communication through the interface is critical for maintaining real time synchronism and voltage regulation.

Table 1.3 summarizes the parameters for the interface, their associated regulation controls and the impact on the interface and power flow.

Parameter	Regulation	Impact

Voltage	Load Tap Changer, Field Exciter	Voltage Stability and Reactive Power
Frequency	Turbine-Governor	Power Flow and Synchronization
Phase Angle	Turbine-Governor	Synchronization with customer network
Real Power	Turbine-Governor, Field Excitation	Real Power demand
Reactive Power	Field Exciter	Reactive power demand
Protection	Relay Console	Breaker Fault Coordination

Table 1.3: Summary of Interface Elements

The interface parameters given in the table above will be the basis for formulating the system requirements in section 3. Figure 1.3 shows the interface and respective interface parameters between the OTEC plant and the customer network.

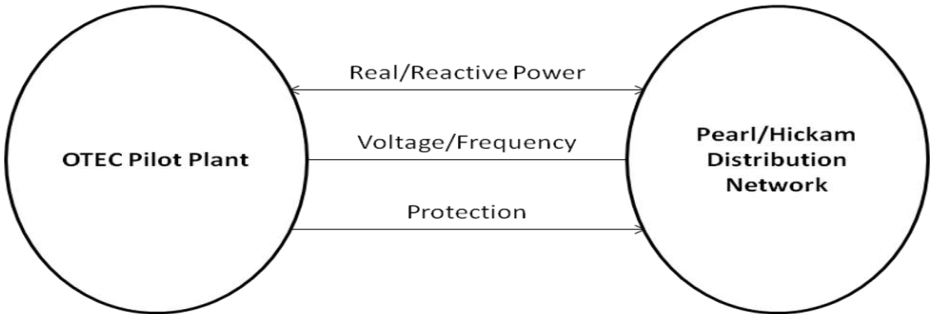


Figure 1.3: Interface between the OTEC plant and customer

1.4 Overview of the OTEC Plant – Customer Grid

The OTEC pilot plant operates by using the temperature differential between the warm surface seawater and deep cold seawater off the coast of Oahu to establish a thermodynamic closed cycle and convert the thermal energy into mechanical work. The closed cycle working fluid is ammonia which is evaporated to drive a turbine-generator. Part of the generated electrical

power is consumed by the platform loads needed for the operation of the thermodynamic cycle (e.g. seawater pumps, lighting, etc…), the balance of the generated power is delivered to the customer via a submarine power cable. With the OTEC pilot plant operating optimally for temperature differentials >20° C, the proposed site location off of Oahu is well suited for this application. Figure 1.4.a shows the proposed site for the OTEC pilot plant.

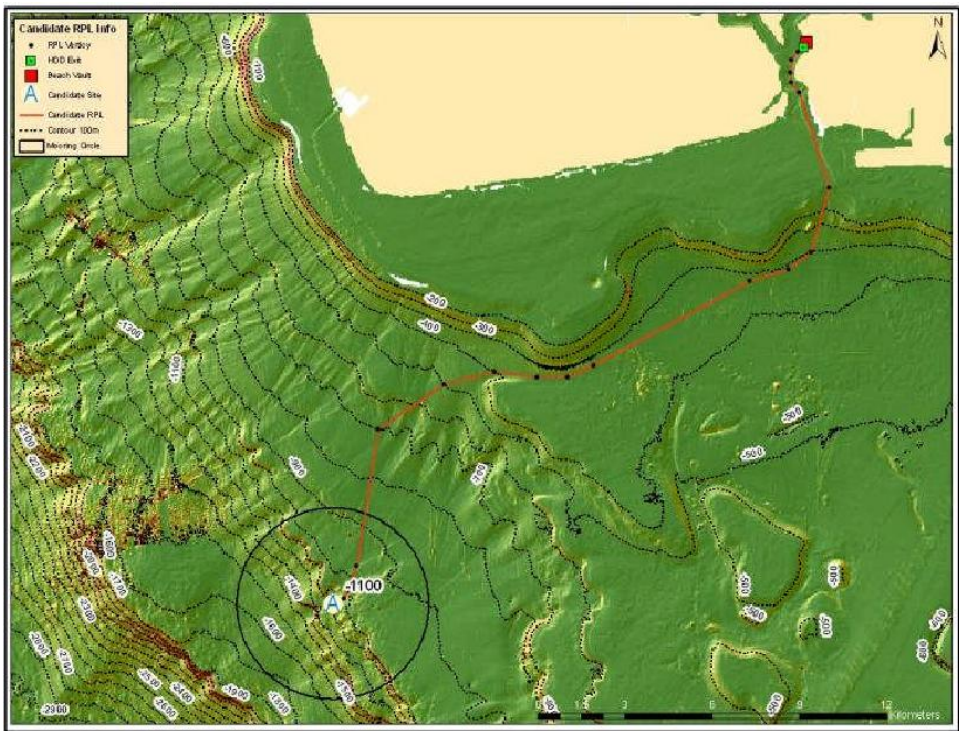


Figure 1.4.a: Proposed OTEC Pilot Plant site with notional cable to shore path

The interface includes the termination of the submarine cable into the Pearl Harbor/Hickam Airfield base. The submarine cable will be terminated at the shore inside an underground cable vault. Inside the vault the submarine cable will transition into a different type of cable more suited for land burial. Reason for the transition is to specify a smaller, less expensive, lighter and more flexible land cable for the urban cable route. A notional cross-section representation of the submarine cable is shown in Figure 1.4.b.

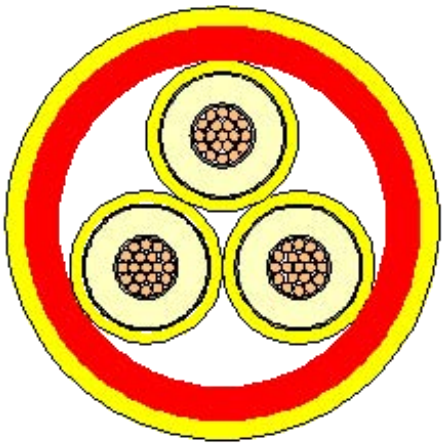


Figure 1.4.b: Notional Submarine Cable Cross Section

The landing site of the submarine cable is determined by several factors. The most important factor is the location of the landing site in relation to the electrical infrastructure of the customer. For the OTEC Pilot Plant project, this results in the submarine cable being routed through the mouth of the Pearl Harbor channel. On Figure 1.4.c, shown below, LS 2 has been selected as the prime candidate for the landing site of the submarine power cable. Once transitioned to a land cable, the final run of the transmission system will connect to the OTEC onshore substation, which is located near the customers “Back Substation” on base. The land cable is to be routed through existing underground ducting (TBR). The “Back Substation” area is preferred because it already has an existing infrastructure and has sufficient land area for the onshore OTEC substation.

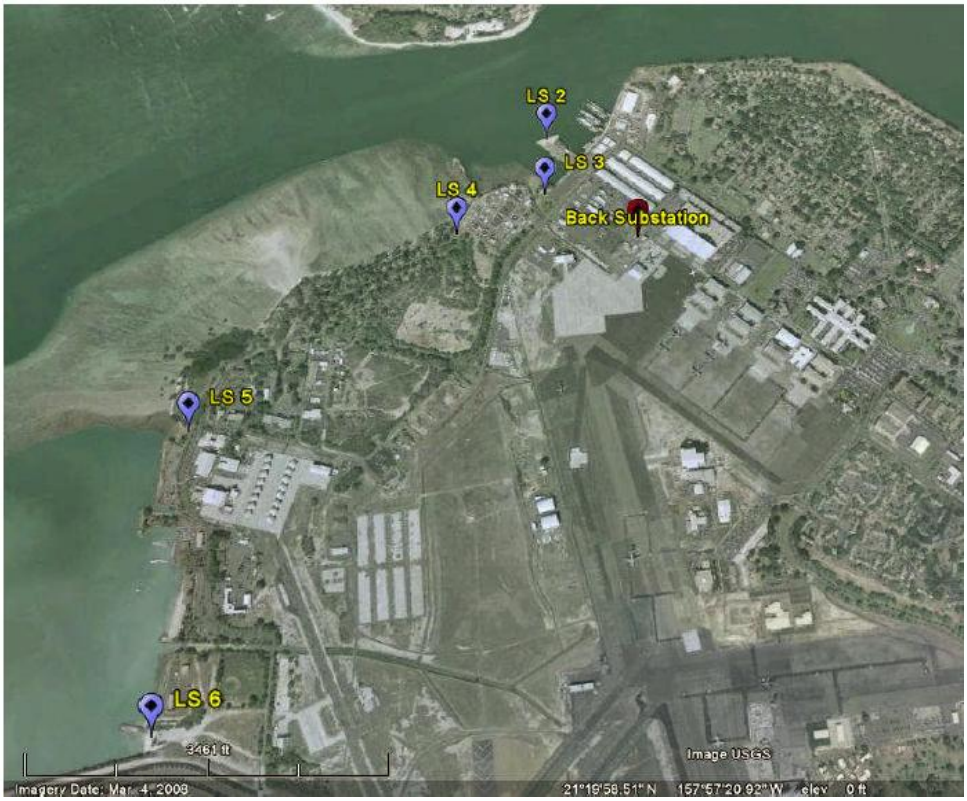


Figure 1.4.c: Hickam Airfield with proposed landing sites identified

The land cable enters the OTEC substation on the side facing the shoreline. Once inside the perimeter of the substation, the land cable is connected to protective switchgear rated for at least 34.5 kV inside the substation building. The secondary terminals of the switchgear are connected to the outdoor transformer, where the transmission voltage is stepped down to 11.5 kV line-line. A load tap changer is installed on the secondary windings of the transformer to compensate for the voltage regulation of the submarine cable. The last element in the substation is the protective switchgear rated for 15 kV line-line. Between the secondary terminals of the OTEC switchgear and the customer switchgear is the point of interconnection. The point of interconnection is an arbitrary line between the two networks that separates liability and control of individual subsystem elements. Figure 1.4.d below is a preliminary layout of the substation foundations. Figure 1.4.e shows the one-line electrical diagram of the shore substation where the interface between OTEC and the customer is established.

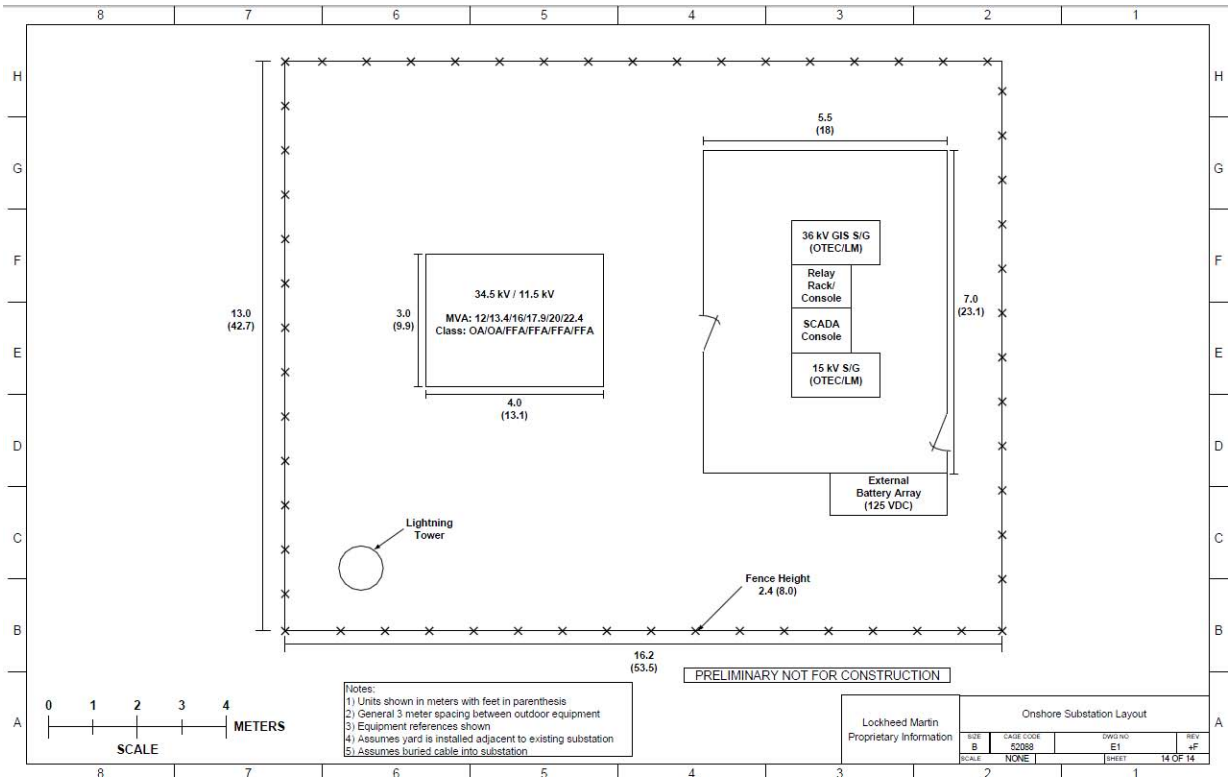


Figure 1.4.d: OTEC Onshore Substation Physical Layout

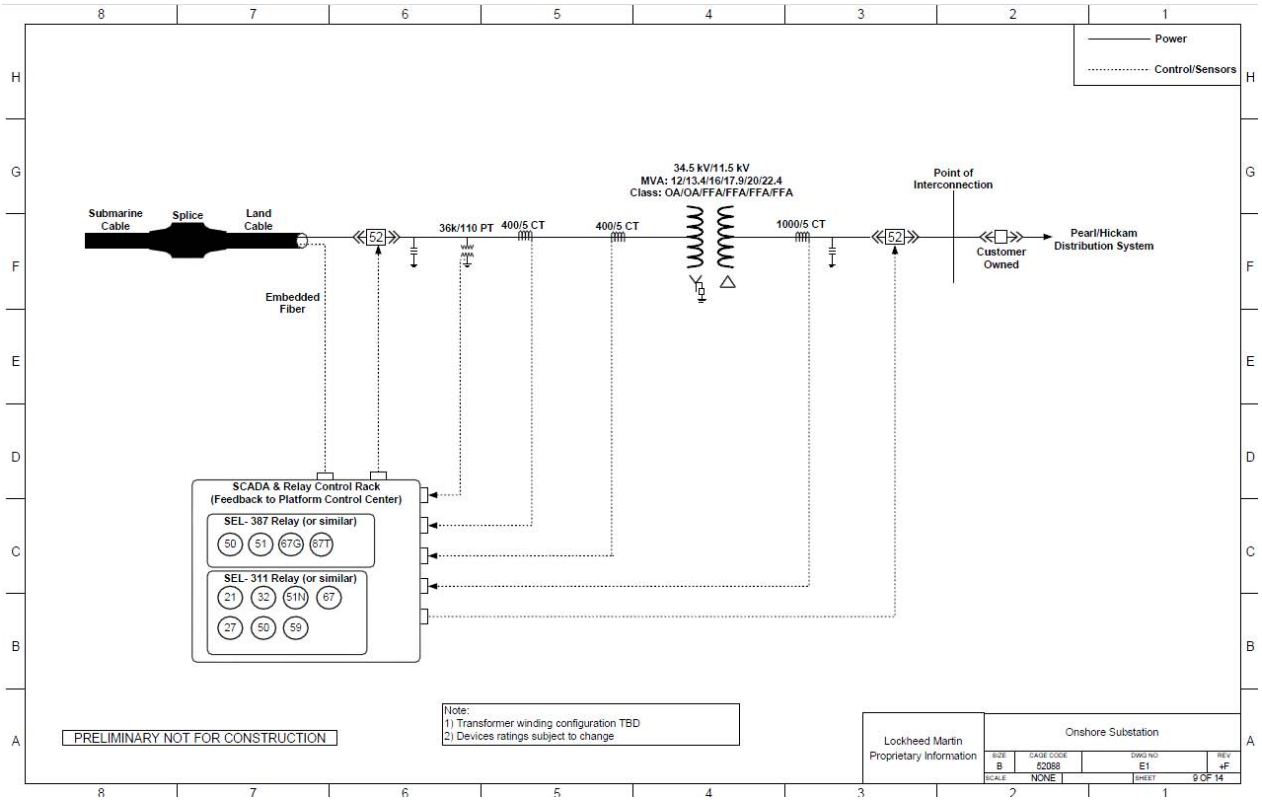


Figure 1.4.e: OTEC onshore substation one-line diagram

The other major interface consist of data exchanges between the OTEC plant and the grid control center, the communication interfaces Communication to between the OTEC plant and the customer will occur using established data link layer standard and protocol required by the customer . The communication interface will define frequency, phase synchronization tolerance, voltage regulation, load control and circuit protection and coordination and dynamic response to transient events. Requirements for interconnecting and synchronization are covered in the next sections.

Section 2 APPLICABLE DOCUMENTS

2.1 Program Documents

The following documents of exact issue shown (identified by revision letter only) and authorized changes from a part of this specification to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this specification, the contents of this specification shall be considered superseding requirements. The documents referenced in this ICD are those required to establish the framework for interconnection of the OTEC Pilot Plant to the customer. As the document evolves during the next phases of the project, more documents will be added to reflect the growing maturity of the interface.

1. OTEC Electrical One-Line Drawing (Revision F)

2.2 Non-Program Documents

Non-program documents are not referenced in this ICD.

2.2.1 Government Documents

Government documents are not referenced in this ICD.

2.2.2 Non-Government Documents

1. Specifications

   a. Hawaiian Electric Company (HECO) Rule No. 19 “Interconnection and Transmission Upgrades.” 09 NOV 2007.

2. Standards

   a. IEEE 1547.2-2008. “IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems.” 15 APR 2010.

3. Drawings

4. Other Publications

   a. Hawaii Public Utilities Commission. “Interconnection Requirements Study for Kahuku Wind Project.” Docket No. 2009-0176.

Section 3 REQUIREMENTS

3.1 Customer Grid Interface

This section covers the interface requirements between the OTEC pilot plant and the customer distribution network. The details of this section will be further refined through the later design stages. At this point it covers at a high-level the requirements necessary to safely and efficiently deliver power through the interface connection.

3.1.1 Purpose

The interface between the OTEC pilot plant and customer grid allows for the transfer of power generated from the platform to the customer onshore. Likewise, the interface will also permit the flow of power from the customer to the OTEC pilot plant for scenarios when the plant generator is offline. The flow of power through the interface will be well regulated through local controls at the interface and power flow controls on the OTEC platform.

3.1.2 Interface type

The interface will be a power flow from the OTEC pilot plant to the customer grid. Electric power will be delivered through the interface nominally at 60 Hz with 11.5 kV AC Line-Line at the interface terminals. Data communications definition at the physical layer and higher layers are TBD at this time as it must be compatible with the customer network and power local power utility grid control network.

3.1.3 Information exchange

Real time data on the state of the interface will be transmitted to the customer and back to the OTEC platform. Vital data will be passed through the interface. Exchange of data will include real and reactive power flow, turbine-generator voltage, frequency, and power flow data. Other informational data will be added to the interchange as required during the later design phases.

3.1.4 Operational Activities

The operation of the interface is handled by two separate, but interconnected, control elements: the turbine-generator controls and the Supervisory Control and Data Acquisition (SCADA). Turbine-generator controls consist of the turbine governor and field exciter. Both of these control elements regulate the power flow out of the OTEC generator. The turbine-governor regulates the generator frequency, which sets the real power flow. Likewise the field-exciter regulates the generator voltage, which sets the reactive power flow. SCADA encompasses the instrumentation and control system that captures all critical signals on both sides of the interface and takes corrective action when necessary. SCADA will regulate voltage at the interface, trip relays during fault events, and monitor the flow of real and reactive power to the customer grid. Further operational activities will be added as the interface design matures.

3.2 Interface Requirements

The interface will require a permanent connection between the OTEC plant onshore substation and the customer distribution network. The power delivery will be provided through 3-phase cables rated for at least 11.5 kV line-line and 400 amps (TBR) for the initial 5 MW pilot plant. For the planned future upgrade to 10 MW pilot plant, the interface will need to either be upgraded to handle 800 amps or a second customer distribution interface will be required. Another option is to initially size the interface for the future 800 amps requirement. This alternative configuration will result in the greatest cost savings in the long term. The interface must also provide protection and isolation of the two systems in the event of a fault. The requirements of the protection element are covered in the later sections of the document.

3.3 System activity requirements

The activity of the interface includes the following categories: synchronization, power flow. And what is called de-synchronization during shut down sequences. Synchronization involves controlling the OTEC voltage, phase and frequency to match the system parameters of the customer grid. The interconnection will occur at the point of interconnection. Synchronization guidelines for distributed generation are contained in IEEE 1547. The key synchronization parameters are frequency, voltage magnitude, and phase angle. Table 3.3 defines the synchronization envelope for the parameters from IEEE 1547. Once the OTEC system is within the parameters in row 3 at the interface point, synchronization breakers can be closed.

Aggregate rating of DR units (kVA)	Frequency difference (Δf, Hz)	Voltage difference (ΔV, %)	Phase angle difference (ΔΦ, °)
0–500	0.3	10	20
>500–1500	0.2	5	15
>1500–10 000	0.1	3	10

Table 3.3: Synchronization parameters from IEEE 1547

Power will either be delivered to the customer or power will be drawn from the customer grid. During this activity, the interface shall maintain the operational envelope in Table 3.3. The regulation of that occurs via the power controls on the turbine-generator and marginally through the load tap changer on the onshore transformer. Any deviation from the operational envelope will result in a loss in synchronization and ceasing of power flow.

The last system activity is de-synchronization. This activity occurs if the OTEC plant and customer grid need to be physically separated from each other. This can occur from periodic maintenance or and emergency condition such as a fault event. For normal maintenance, de-synchronization will occur after power has been successfully offloaded to another power source (i.e. the HECO grid for the customer distribution, diesel generator for the OTEC plant). Once power flow has halted, the synchronization breaker will open and the two systems will be separated.

3.3.1 Operational Requirements

The operational requirements of the interface are supervised by the SCADA system. SCADA Equipment greatly minimizes human errors and operating costs, while at the same time it improves the OTEC System performance and reliability. The SCADA is provided with uninterruptable power using a battery power energy storage system. The battery shall have a charge capacity and terminal voltage of 25 Ah (TBR) and be provide 125 V DC (TBR) which is a standard for substations. The protective relays shall operate in less than 3, 60 Hz cycles (TBR), and shall interrupt low and high voltage faults. In the event a fault occurs, redundant protection shall be required. In addition to SCADA, the turbines governor and the generator field exciter controls will be integrated into the communication interface. As the design becomes more mature additional requirements for the turbine-generator controls will be added to the interface.

3.3.2 Equations/models

The equations and modeling that governs the interface are well known for Power System analysis. The modeling of the interface is handled through power flow analysis. The necessary equations for this analysis will be defined as the interface is further defined.

3.4 Responsibility Summary

3.4.1 OTEC System Element to Customer System Element

The interface between the OTEC pilot plant and the customer is the point of interconnection between two manual disconnect switches. The last part of the control system between the two systems are circuit breakers on both ends of the disconnect switches. The disconnect switches provide the physical separation between the two systems and the circuit breakers provide the electrical isolation. The physical interface is shown in Figure 3.4.1.

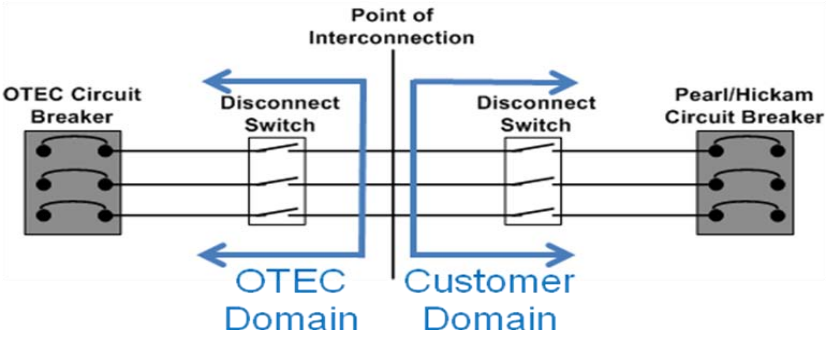


Figure 3.4.1: Point of Interconnection for the OTEC-Grid interface

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3.4.2 Performance requirements

3.4.2.1 Ramp Rate

OTEC shall ensure that the ramp rates are less than the following limits for all conditions including start up, normal operations, and shut down for the following periods.

a. Maximum Ramp Rate Upward of 2.0 MW/minute for all periods except during

Early Morning Low-Load Periods (Midnight to 4:00 am) where Maximum Ramp

Rate Upward is 1 MW/minute.

b. Maximum Ramp Rate Downward of 2.0 MW/minute for all periods except during

Evening Periods (4:00 pm to 8:00 pm) where Maximum Ramp Rate downward is lower at 1 MW/minute.

3.4.2.2 Power Fluctuation Rate

OTEC shall ensure that the power fluctuation rate is less than the following limit for all conditions including start up, normal operations, and shutdown;

a. Instantaneous: 1 megawatt/2-second

b. Sub-minute Average: an average of 0.3 megawatt / 2-second for any 60-second period.

3.4.2.3 Under-Voltage Ride Through

OTEC will be required to provide under-voltage ride through capability (fault ride through). The OTEC will behave as follows during an under-voltage disturbance ("V" is the voltage of any or all of the three phases at the Point of Interconnection):

• For 0.80 pu < V < 1.00 pu, the OTEC remains connected to the Customer network.

• For 0.75 pu < V < 0.80 pu, the OTEC remains connected to the Customer network If "V" remains continuously in this range for less than or equal to 2 seconds.

• For 0.00 pu < V < 0.75 pu, the OTEC remains connected to the Customer network If "V" remains continuously in this range for less than or equal to 600 milliseconds,

• When the voltage at the Point of Interconnection (POI) recovers above the voltage range described in each bullet above, the protection scheme should reset the timing function to zero as rapidly as possible, but no more than 1 cycle.

3.4.2.4 Over-Voltage Ride Through

The OTEC will be required to provide over-voltage ride through capability. The OTEC will behave as follows during an over-voltage disturbance ("V" is the voltage of any or all of the three phases at the Point of Interconnection):

• For 1.00 pu < V < 1.10 pu, the OTEC remains connected to the Customer network.

• For 1.10 pu < V < 1.15 pu, the OTEC remains connected to the Customer network for no less than 30 seconds.

• For 1.15 pu < V, the OTEC may initiate disconnection from the Customer network If "V" remains In this range for more than as allowed by the manufacturer's recommended time interval.

• When the voltage at the POI recovers below the voltage range described in each bullet above, the protection scheme should reset the timing function to zero as rapidly as possible, but no more than 1 cycle.

3.4.2.5 Transient Ride Through

The OTEC shall be designed such that the transient stability of the Customer network Is maintained for (1) a three-phase fault located anywhere on the Customer network and lasting up to 36 cycles; and (2) a single line to ground fault located anywhere on the Customer network and lasting up to 36 cycles. During the transient ride-through period, all OTEC equipment shall provide the full fault current capability of the piece of equipment for the entire duration of the ride-through period and shall not cut-out, curtail, or otherwise limit its current output during this ride-through period.

3.4.2.6 Under-frequency protection Coordination

The OTEC will be required to coordinate its under-frequency protection settings with Customer network's under-frequency load shedding scheme. The OTEC will behave as follows during an under-frequency disturbance ("f" is the system frequency at the Point of Interconnection):

• For 57.0 < f < 60.0 Hz, the OTEC remains connected to the Customer network.

• For 56.0 Hz < f < 57.0 Hz, OTEC remains connected to the Customer network if "f" remains in this range continuously for less than or equal to 6 seconds.

• For f < 56.0 Hz, the OTEC may Initiate disconnection from the Customer network immediately.

• When the frequency at the POI recovers above the frequency range described in each bullet above, the protection scheme should reset the timing function to zero as rapidly as possible, but no more than 1 cycle.

10. OTEC will be required to coordinate its over-frequency protection settings with HECO's over-frequency ride-through requirements. The OTEC will behave as follows during an over-frequency disturbance ("f" is the system frequency at the Point of

Interconnection):

• For 60.0 < f < 61.5 Hz , the OTEC remains connected to the Customer network.

• For 61.5 Hz s f < 63.0 Hz, the OTEC remains connected to the Customer network if "f" remains in this range for less than or equal to 10 seconds,

• For f > 63.0 Hz, the OTEC may Initiate disconnection from the Customer network immediately.

• When the frequency at the POI recovers below the frequency range described in each bullet above, the protection scheme should reset the timing function to zero as rapidly as possible, but no more than 1 cycle.

3.4.3 Design requirements

The design requirements for establishing and maintaining the interface are listed below. For the OTEC interface, numerous studies are required to ensure compliance with HECO for stable power flow. This includes, but is not limited to, transient stability, short circuit analysis, small signal analysis, and power flow. The following abnormal system conditions must be adjusted for during the design phase.

3.4.3.1 Voltage flicker

Any voltage flicker at the Point of Interconnection caused by the OTEC plant shall not exceed the limits defined by the "Borderline of Visibility Curve," Identified In IEEE Standard 519-1992, or latest version "Recommended Practices and Requirements for Harmonic Control In Electrical Power Systems."

3.4.3.2 Harmonic distortion

Harmonic distortion at the Point of Interconnection caused by the OTEC plant shall not exceed the limits stated in IEEE Standard 519-1992, or latest version "Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems." The OTEC plant will be responsible for the installation of any necessary controls or hardware to limit the voltage and current harmonics generated by the OTEC plant.

3.4.3.3 Transient stability

The OTEC project should provide the customer power flow and transient stability models for the planned project that can be used for normal planning and operational studies. The transient stability model should be provided and updated by OTEC for the current and successive transient modeling applications used by the customer. The models should allow customer to conduct, both now and in the future, normal line fault and trip simulations or unit trip simulations to determine the performance of the customer network, for events both near and far from the OTEC project. These models will become more important as the customer attempts to integrate additional resources into their network.

3.4.3.4 Electro-Magnetic Transient Program (EMTP)

The OTEC project should provide Customer an EMTP model for the planned project that can be used for planning and design verification studies.

3.4.3.5 ASPEN One-Liner Model

The OTEC project should provide Customer with an ASPEN One-Liner model for the planned project that accurately depicts the voltage and current magnitude and phase angles for

symmetrical and asymmetrical faults anywhere In the CUSTOMER system directly connected to the OTEC.

3.4.3.6 OTEC Offline

When the system configuration is such that the OTEC project is not connected in its normal operating configuration, the OTEC project will remain off line until the normal operating configuration is restored.

3.5 Functional Requirements

3.5.1 Transmission Cable

The transmission system, in seawater, shall have a minimum efficiency of 97% between transformers. High efficiency is important for reducing line losses and will decrease equipment costs. Also, the cable manufacture should be aware of thermocline in seawater on riser and seafloor portion to determine how efficiency is affected. The transmission system shall deliver 5MW-average net power to shore for the customer. However, driven by a top level requirement, the transmission system during maximum conditions shall deliver 12.7 MW net to shore for the customer. The submarine cable functional requirement relevant to the interface on the customer base is given in Table 3.5.1.

Power Transmission ID	Requirement	Rationale
PT_01	The transmission subsystem shall transfer power for the OTEC platform to shore in an efficient manner.	High efficiency important for reducing line losses and decreasing equipment costs.
PT_02	The transmission system shall have a minimum efficiency of 97%, between transformers, for the initial 5 MW OTEC system.	Transmission system is optimized for the initial 5 MW plant, rather than the future upgrade to 10 MW. Important for voltage sizing of cables.
PT_03	The transmission system shall deliver 5 MW-average-net power to shore for the customer.	Driven by top level requirements. Net power is measured on-shore.
PT_04	The transmission system shall deliver a maximum of 12.7 MW-net to shore for the customer.	Driven by top level requirements for future upgrade to 10 MW-ave-net. Net power is measured on-shore.
PT_05	Submarine cable shall operate efficiently in a temperature range of 28 °C to 4 °C ambient seawater temperature.	Cable manufacturer should be aware of thermocline on riser and seafloor portion to determine how efficiency is affected.

Table 3.5.1: Submarine Cable, Functional Requirements

3.5.2 Onshore Substation

The onshore substation shall serve as an interface between the OTEC plant and the customer utility, and shall be constructed by an experienced substation subcontractor. For safe and reliable delivery of power to the customer, a minimum amount of electrical equipment is required. The responsibility for servicing, maintaining, and operating the substation shall be the OTEC plant operators. Allowances shall be made for the customer utility to install equipment in the substation necessary to maintain safe and reliable delivery of power to their system.

3.6 Performance Requirements

The interface will provide power from the OTEC pilot plant to the customer grid. It will operate on the interface performance of 11.5 kV +/- 3% line-line terminal voltage and 60 Hz system frequency. The interface will deliver 5 MW-average-power through the customer interface throughout the course of the year. This output will vary from a minimum of 3.2 MW to a maximum of 6.3 MW throughout the course of the year during normal operation. This variation is due to the natural cycle of the ocean temperature gradient. Output will vary depending on situational conditions. The OTEC platform will require periodic maintenance that will result in an intentional reduction in power output and/or complete shutdown of the OTEC system. These performance conditions will be further quantified during the next phase of the design.

3.7 Configuration Requirements

The configuration of the interface encompasses the electrical set points and data set points for power and information exchange. For the electrical set points, the operational voltage and frequency must be set to 60 Hz and 11.5 kV +/- 3% respectively. Any deviations from this can result in a loss in synchronization and damage to the interface. Protective configurations, such as relays shall be set, such that they initiate for fault conditions and not for “false” trip events. The specific set point for these protection systems is TBD at this point as it requires further detail.

3.8 Physical Requirements

The physical requirements are grouped into two categories: transmission cable and onshore substation. The following sections will cover the requirements for these two systems:

3.8.1 Transmission Cable Equipment

3.8.1.1 Seafloor Cable

The submarine cable shall operate efficiently in an environment with a seafloor thermal resistivity of 1.2Km/W (TBR). Ground resistivity is required to calculate cable efficiency. During transmission to shore the submarine cable shall run to shore through horizontal drilling (TBR).

3.8.1.2 Cable Vault

The cable vault shall serve as the interface between the submarine cable and the land cable, and shall not contain any active cable protection equipment. All active protection equipment (i.e. switchgear) will be contained in the platform and onshore substations.

3.8.1.3 Land Cable

The land based cable shall be used to deliver OTEC power from the submarine cable to the onshore substation. Transition from submarine cable to land cable is necessary to run the cable through the land route. Routing the submarine cable through the ground is expensive and impractical. The land based cable shall be directly buried into the ground (TBR), have a rated voltage of 34.5 kV and adhere to ICEA insulator and conductor standards. Preliminary feedback from the customer indicated overhead lines are not permitted.

3.8.2 Onshore Substation Equipment

3.8.2.1 Transformers

The onshore substation transformers shall have a maximum rating of 20 MVA. The current transformer is sized based off the most current data for net output power from the OTEC generator. The onshore substation transformers shall have high and low voltage windings that match the customer distribution voltage. In support of a 10 MW upgrade, the onshore substation transformer shall support both the initial 5MW power requirement, and the future 10 MW power requirement. Table 3.8.2.1 provides the high-level submarine cable transformer requirements.

Onshore Substation ID	Requirement	Rationale
OS_09	Onshore substation transformer shall have a maximum rating of 20 MVA.	Transformer sized based off current Makai data for net power out (12.7 MW-net-max) with 125% extra margin (for transient and derating margin) and assuming a .8 power factor (for reactive power burden). This results in 12.7*1.25/.8 = 19.84 MVA. It is then rounded up to the next size available (i.e. 20 MVA).
OS_10	Onshore substation transformer shall have a high voltage winding rated for nominal 34.5 kV and low voltage winding rated for a nominal 11.5 kV.	Match OTEC power plant voltage with customer distribution voltage.
OS_11	Onshore substation transformer shall be insulated and cooled with an immersed liquid oil.	Oil type transformers are preferred over the alternative dry due to higher efficiency, better heat transfer, lower noise, smaller footprint, and lower life-cycle costs.

Table 3.8.2.1: Onshore Substation, Transformer Requirements

3.8.2.2 Switchgear

The onshore substation switchgear shall use medium voltage GIS switchgear (TBR). GIS switchgear is strongly preferred over the alternative air insulated, and provides higher arc resistance with a smaller footprint. The onshore switch gear shall be rated for 38 kV max, and have a nominal current rating of 1000 Amps. Table 3.8.2.2 provides the high-level submarine cable switchgear requirements.

Onshore Substation ID	Requirement	Rationale
PS_14	Onshore substation shall use medium voltage GIS switchgear TBR.	Strongly preferred over the alternative air insulated. Provides higher arc resistance with a smaller footprint.
PS_15	Onshore switchgear shall be rated for 38 kV max.	Sized highest voltage level (34.5 kV) and rounded up to the next highest ANSI/NEMA voltage class 38 kV.
PS_16	Switchgear circuit breakers shall have a nominal current rating of 1000 Amps	Sized based off maximum current on 11.5 kV branch @ rated transformer power (20 MVA)
PS_17	Switchgear breakers and busbar shall withstand short circuit currents of <40 kA for < 3 seconds TBR.	Standard rating for medium voltage switchgears. To be reviewed as short circuit analysis is performed for OTEC system.

Table 3.8.2.2: Onshore Substation, Switchgear Requirements

3.9 Operational Modes

The interface will operate on three modes of operation: power delivery, power receiving, and stand alone. Power delivery mode of operation is when power is being delivered from the OTEC platform *to* the customer utility. This operation will result in positive power flow from the platform to the interface. This operation shall be the normal operation of the interface. Power receiving mode of operation is when the power is received to the OTEC platform from the customer utility. This mode of operation is not typical and only occurs when the OTEC power plant if offline for extended maintenance. The final mode of operation is stand alone. This operation results in no power flow through the interface, both system operate with no transfer of power between them. This mode of operation is typical for testing of the OTEC pilot plant for various conditions.

3.9.1 Equations/Models

The modeling parameters for the interface will be defined during the later design phases of the project. They essential modeling activity will included short circuit analysis, transient stability study, and power flow analysis. Once the system elements and the interface is more mature, work will begin on modeling the systems.

3.10 Design and Construction Requirements

The design and construction requirements are grouped into two categories: transmission cable and onshore substation. The following sections will cover the requirements for these two systems.

3.10.1 Submarine Cable

3.10.1.1 Environment

The submarine cable shall have negligible effects on marine life and habitat, ensuring minimum impact on the environment. EMF field effects must be verified. The submarine cable shall not use any fluid filled insulators, due to their high risk of leakage.

3.10.2 Onshore Substation

3.10.2.1 Protection Equipment

Protective relays shall interrupt faults that occur on the submarine cable, land cable, and inside the substation. Isolating faults from impacting the customer's network and/or the OTEC platform is of the utmost importance. Protective relays shall interrupt faults that occur on the customer utility from damaging OTEC power equipment. Backup protection is needed in the event a fault occurs on the utility network and the utilities protection fails to isolate the fault properly. Relays shall respond appropriately to common fault events (e.g. over-current, under-current, overvoltage, etc.). Common operational criteria for relays and protective equipment will be followed. All protective relays shall operate in less than 3, 60 Hz cycles (TBR).

3.10.2.2 Environment

The onshore substation's environment shall be kept to a minimum by reducing the footprint, thus reducing the impact of the surrounding environment. When possible, environmentally benign oils shall be used for lubrication.

Section 4 VERIFICATION

4.1 Verification Methods

The requirements identified in Section 3 of this ICD shall be verified by a combination of the standard test metrics: inspection, simulation, measurement, and testing. The verification methods of each metric are given in the requirements tables of Section 3. This section will further expand on the verification task and look at what is needed to satisfy each of the requirements listed in the previous section.

4.2 System Element verification

The grid interface between the OTEC plant and the customer will be verified through a set of operational phases. The first phase consists of bringing the OTEC plant online in a standalone operation. During standalone, the OTEC will not be connected to the customer and will dissipate all power generated as heat into a dynamic load bank installed on the platform. This phase will test the operation of the turbine-generator, governor and field excitation, and power infrastructure on the OTEC pilot plant. Also during the first phase, the onshore interface will be tested by energizing the onshore substation from the customer grid. The power draw will be negligible, but serves the purpose of verifying the operation of the physical interconnection. The second phase will involve operating the plant in stand alone with the submarine cable and substation onshore now energized by the platform turbine generator. This phase expands off of the first phase by simultaneously testing the turbine generator and the connection to shore. For this phase, the breaker between the customer and OTEC plant will be open. The last phase shuts off the load bank and interconnects the pilot plant to the customer grid. The last phase completes the interconnection to the customer. A summary of each phase is given in Table 4.2.

	Stand-Alone	Grid Connected	Load Bank	Substation Energized
Phase I	Yes	No	Yes	Yes
Phase II	Yes	No	Yes	Yes
Phase III	No	Yes	No	Yes

Table 4.2: System Verification Test Phases

4.3 Intersystem Element Verification

The requirements that will be verified by Intersystem element demonstration are identified in the intersystem element demonstration column of Table 4.3 by the demonstration number. The referenced demonstrations will be defined in the system Integrated Test Plan (SITP).

4.3.1 Ramp Rate

From section 3.4.2.1

This requirement will be the part of turbo-generator design. Factory tests shall be done to assure that the requirements are met.

4.3.2 Power Fluctuation Rate

From section 3.4.2.2

This requirement will be the part of turbo-generator design. Factory tests shall be done to assure that the requirements are met.

4.3.3 Under-Voltage Ride Through

From section 3.4.2.3

This test shall demonstrate that the OTEC plant ceases to energize the customer network when the voltage is below the limits as specified in section 3. Interconnection systems provided with field adjustable set points shall also be tested at the minimum, midpoint, and maximum of the adjustable set point ranges. These tests shall be conducted using either the simulated utility or secondary injection method.

4.3.4 Over-Voltage Ride Through

From section 3.4.2.4a

Verification test shall demonstrate that the OTEC plant ceases to energize the customer network when the voltage exceeds the limits as specified in section 3. Interconnection systems provided with field adjustable set points shall also be tested at the minimum, midpoint, and maximum of the adjustable set point ranges. These tests shall be conducted using either the simulated utility or secondary injection method.

4.3.5 Transient Ride Through

From section 3.4.2.5

Verification test shall demonstrate that the OTEC plant stays on line during the transient condition as defined above. Interconnection systems provided with field adjustable set points shall also be tested at the minimum, midpoint, and maximum of the adjustable set point ranges. These tests shall be conducted using either the simulated utility or secondary injection method.

4.3.6 Under-Frequency Protection Coordination

From section 3.4.2.6

Verification test shall demonstrate that the OTEC under-frequency protection is coordinated with the customer network's under-frequency load shedding scheme. Interconnection systems provided with field adjustable set points shall also be tested at the minimum, midpoint, and maximum of the adjustable set point ranges. These tests shall be conducted using either the simulated utility or secondary injection method.

4.3.7 Harmonic distortion

From section 3.4.3.2

Harmonic distortion requirements will be part of the specifications for all major electrical hardware installed on the pilot plant. Total harmonic distortion (THD) < 5% will be used as the initial baseline maximum for all hardware (TBR). Measurements will be performed throughout the pilot plant to keep track of the THD and make sure it is within limits to prevent damage and/or life shortening of equipment such as generators, transformers, etc…

4.3.8 OTEC Offline

From section 3.4.3.6

Verification test will check the cease to energize (OTEC offline) functionality by operating a load interrupting device and verify the equipment ceases to energize its output terminals and does not restart/reconnect for the required time delay. The test shall be performed on each phase individually.

4.3.9 Protection from EMI

From section 3.10.1.1

Verification of EMI at the interface shall be tested in accordance with IEEE Std C37.90.2-1995 to confirm that the results are in compliance with 4.1.8.1. The influence of EMI shall not result in a change in state or mis-operation

4.3.10 Synchronization

From section 3.9

This test shall demonstrate that at the moment of the paralleling-device closure, all three parameters in Table 5 of IEEE 1547 are within the stated ranges. This test shall also demonstrate that if any of the parameters are outside of the ranges stated in the table, the paralleling-device shall not close.

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-38
OTEC Power Generation and Transmission FMECA Revision 0
OTEC-2010-001

17 September 2010

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Failure Mode ID	Item Name	Failure Mode	Mission Phase/Op Mode	Failure Effects		Failure Detect Method	System Abort (SA) Failure	Criticality Analysis			RPN	Comments
				Local Effects	End Effects			Occ. Level (1-10)	Sev. Level (1-10)	Detect Level (1-10)		
OPS1-1	Ammonia Interface Platform-Remora	Leak	All	Ammonia in air	Loss of pressure, degradation of performance	Ammonia sensors, and pressure sensors	No	4	1	2	8	Need alarm and lights
OPS1-2	Remora Ammonia Piping	Not Properly purged	Initial Startup	non-ammonia compounds in ammonia system	degradation of performance	Pressure sensors (redunant)	No	3	1	2	6	Need to be prepared to purge for system during operation…should accululate in demistor and condenser CB: Higher condenser pressure is an indicator of the presence of non-condensabe gases
OPS1-3	Remora Ammonia Piping	Leaks, before connecting to platform	Initial Startup	Loss of pressure in the system	Delay in connection	Pressure sensors	No	2	1	2	4	Need alarm and lights
OPS1-4	Remora Ammonia Piping	Leaks, after connection, before filling	Initial Startup	Loss of pressure in the system	Delay in pipe filling	Pressure sensors	No	2	1	2	4	Need alarm and lights
OPS1-5	Ammonia Interface Platform-Remora	Break due stress	All	Leaks ammonia vapor	Loss of pressure, degradation of performance, plant shutdown	Assume ammonia vapor sensors, pressure sensors, and strain gauges should alert to potential problems	Yes	2	3	5	30	Need alarm and lights. Break/leak will occur at neck, critical during assembly, should be protected during design
OPS1-6	Topside Ammonia Piping	Hydrostatic overpressure	Non running states	Increased pressure due to increased temperature in trapped liquid	Pipe burst releasing ammonia	Pressure sensors	No	2	3	5	30	Need to add pressure relief valves per code B31.5; alarms and lights CB: Large vapor pipes will be hard to fill with liquid ammonia. This is very unlikley.
OPS1-7	Ammonia System	Leak, slow/minor	All	Ammonia in air/water	Slow loss of ammonia volume, possible environmental impacts, insignificant performance impact	Ammonia sensors or pH sensors (if located near leak), otherwise, ammonia mass book keeping discrepancy	No	4	1	7	28	Need alarm and lights. CB: There is perfromance problem due to loos of inventary that can cause ammonia pumps to run dry and damaged. Inventary monitoring is MUST..
OPS1-8	Ammonia System	Leak, major	All	Ammonia in air/water	Loss of ammonia volume, performance impact, environmental impact, plant shutdown	Pressure sensors, ammonia sensors or pH sensors (if located near leak)	Yes	2	5	2	20	Need alarm and lights. CB: See note above - but on a shorter time scale.

Failure Mode ID	Item Name	Failure Mode	Mission Phase/Op Mode	Failure Effects		Failure Detect Method	System Abort (SA) Failure	Criticality Analysis			RPN	Comments
				Local Effects	End Effects			Occ. Level (1-10)	Sev. Level (1-10)	Detect Level (1-10)		
OPS1-9	Ammonia System	External Damage	All	Ammonia in air/water	Loss of ammonia volume, performance impact, environmental impact, plant shutdown	Pressure sensors, ammonia sensors or pH sensors (if located near leak)	Yes	3	5	5	75	Need alarm and lights
OPS1-10	Pressure Sensor - Control	Inaccurate or no readings	Operation	Erroneous commands sent to actuation	Performance degradation	Redundant sensor	Yes	3	3	2	18	
OPS1-11	Pressure Sensor - Monitoring	Inaccurate or no readings	All	None	Loss of insight into system (i.e. impending failures) and data collection	Redundant sensor	No	3	1	2	6	
OPS1-12	Temperature Sensor - Control	Inaccurate or no readings	Operation	Erroneous commands sent to actuation	Performance degradation or shutdown	Redundant sensor	Yes	3	4	2	24	
OPS1-13	Temperature Sensor - Monitoring	Inaccurate or no readings	Operation	None	Loss of insight into system (i.e. impending failures) and data collection	Redundant sensor	No	3	1	2	6	
OPS1-14	Ammonia Level Sensors	Inaccurate or no readings	Operation	Erroneous commands sent to actuation	Performance degradation or shutdown	Redundant sensor	Yes	3	4	2	24	
OPS1-15	Ammonia Tank	Leak around	All	Ammonia in water	Loss of ammonia volume, performance impact, environmental impact		No	1	1	2	2	Detect pre use?
OPS1-16	Turbine Bypass	Fails Open	Operation	Turbine Speed Decreases	Loss of generator, and plant shutdown	Mass flow through bypass (or turbine)	Yes	2	6	2	24	discussion with turbine supplier. Turbine/Generator generally has build-in safe operating controls and
OPS1-17	Turbine Bypass	Fails Closed	Operation	Turbine Speed Increase	Shut down for repair	Mass flow through bypass (or turbine)	Yes	2	4	2	16	Trottle Valve Closes
OPS1-18	Turbine	Controls Logic Failure	Operation	Erroneous commands sent to actuation	Performance degradation or shutdown, possible equipment damage	Sensor Feedback	Yes	2	4	5	40	
OPS1-19	Turbine	Sensor Failure	Operation	Erroneous commands sent to actuation	Performance degradation or shutdown, possible equipment damage	Redundant sensor	Yes	2	4	2	16	
OPS1-20	Turbine	High motions cause structural failure	All	Structural failure of a mounting component	System Shutdown, possible ammonia leaks	Accelerometers?	Yes	2	5	5	50	
OPS1-21	Turbine damage	Structural failure due to motions	Operation	damage of a turbine vain	Turbine Damage, plant shutdown	Vibration, accelerometer	Yes	2	5	5	50	Weather Critiera for shut down
OPS1-22	Turbine blade	Errosion due to ammonia droplets in vapor	Operation	Pitting and damage to blades	Decrease turbine performance, extreme cases loss of blade and turbine damage	Optical? or Quality/thermo calculation	No	3	3	6	54	

Failure Mode ID	Item Name	Failure Mode	Mission Phase/Op Mode	Failure Effects		Failure Detect Method	System Abort (SA) Failure	Criticality Analysis			RPN	Comments
				Local Effects	End Effects			Occ. Level (1-10)	Sev. Level (1-10)	Detect Level (1-10)		
OPS1-23	Turbine	Bearing Failure	Operation	Bearings unable to function properly	Degradation of performance, possible damage to other components	Vibration, temperature	Yes	3	7	4	84	CB: Vibration sensor should be installed.
OPS1-24	Turbine Skid	Ammonia-Oil Separator	Operation	Coat Heat Heat Exchangers	Performance Degredation	Ammonia testing - periodic, oil sump level	No	3	4	6	72	testing may be manual? - need to make sure we take care of it immediately CB: Ask for douple seal with air purging to avoid oil leaking into ammonia. Oil in ammonia will cause depositon of oil in heat exchanger that cannot be cleaned easily.
OPS1-25	Turbine and Generator	Low oil pressure	Operation	Bearings damage	plant shutdown	Pressure sensors	Yes	3	7	2	42	
OPS1-26	Generator	Bearing Failure	Operation	Bearings unable to function properly	Degradation of performance, possible damage to other components	Vibration, temperature	Yes	3	7	2	42	
OPS1-27	Generator	Shorting	Operation	damage to generator	Plant Shutdown, possible fire	Current, Fire/spark detector	Yes	3	7	2	42	
OPS1-28	Electrical Breaker	Fails Open	Operation	Open electrical circuit	Plant offline	current	Yes	1	3	2	6	Need to make sure that controls prevent overspeed
OPS1-29	Underwater Cable	Cable Degredation or Damage	All	Water in insulation, corrosion of cable	No immediate effect, but will increase the chance of cable damage	Visual Inspection, Increased Impedance in cable	No	4	3	8	96	
OPS1-30	Underwater Cable	Cable Breaking	Operation	No connection to the grid	Turbine Overspeed Condition, no connection to grid	current	Yes	2	8	2	32	
OPS1-31	Electrical System	Shorting	Operation	damage to equipment with short	Open Breaker, Perhaps Fire	current	Yes	3	7	2	42	
OPS1-32	Electrical Connector	Failure of connection	Operation	Loss of power to device	Possible system shutdown	current	Yes	4	4	2	32	
OPS1-33	Grid	Loss of other power generator	Operation	Higher Load on Generator	Underfrequency condition -> overheating generator	frequency change	Yes	5	4	2	40	
OPS1-34	Transformers	Oil leakage	Operation	Less thermal dissipation in transformer can	Overheating, transformer damage	pressure	No	2	2	2	8	
OPS1-35	Transformers	Cooling system failure	Operation	Less thermal dissipation in transformer can	Overheating, transformer damage	temperature	No	2	2	4	16	
OPS1-36	Transformers	Instrumentation Failure	Operation	Inaccurate or no sensor readings	Possible system shutdown, possible damage to equipment	pressure, temp	No	2	3	9	54	
OPS1-37	Transformers	Oil Pump Failure	Operation	Less thermal dissipation in transformer can	Overheating, transformer damage	pressure, temp	No	2	2	2	8	

Failure Mode ID	Item Name	Failure Mode	Mission Phase/Op Mode	Failure Effects		Failure Detect Method	System Abort (SA) Failure	Criticality Analysis			RPN	Comments
				Local Effects	End Effects			Occ. Level (1-10)	Sev. Level (1-10)	Detect Level (1-10)		
OPS1-38	Electronics Controls	Cooling system failure	Operation	Less thermal dissipation in electronics	Overheating, electronics damage	temperature	No	2	2	5	20	
OPS1-39	Wiring	Miss wiring	Initial Startup	potential damage to miswired component	plant shutdown	pre-startup testing	Yes	3	5	4	60	
OPS1-40	Electronics	Ground Fault	Operation	damage to electronics	Open Breaker, Perhaps Fire	Ground Fault Monitoring	Yes	2	3	2	12	
OPS1-41	Electrical	AC currents flowing through system	Operation	corrosion	plant shutdown for maintenance	None?	Yes	2	4	10	80	
OPS1-42	Electrical System	External Damage	All	shorted or open wires	damage to components	current	No	2	4	5	40	
OPS1-43	Electronics	Ammonia Leak Near Electronics	All	corrosion of wire near ammonia leak	damage to components	ammonia sensors	No	2	4	2	16	Need alarm and lights
OPS1-44	Heat Exchanger	Ammonia Leaking in process water	All	Ammonia in water	performance degradation, corrosion	pH sensors, pressure	Yes	2	3	4	24	CB: Accelrated localized corroison by seawater/ammonia mixture can be serious.
OPS1-45	Heat Exchanger	Pitting/Corrosion	All	decrease heat transfer, possible ammonia leaks	plant performance degradation, possible plant shut down, HX damage	visual inspection	Yes	5	8	7	280	CB: Pitting corroiosn will not impact performance. Potential leak that will cause plant shutdown and subsequent repair/replacement of HXs is a major impact with significnat costs.
OPS1-46	Heat Exchanger	Fouling	All	decrease heat transfer, possible corrosion issues	plant performance degradation, HX damage	visual inspection, thermodynamic values	Yes	5	5	3	75	CB: Unexpected accelerated biofouling of evaporator due to change in biological activities of surafce warm seawater is a major concern. Biofouling monitor is highly recommended.
OPS1-47	Heat Exchanger	Water side Single Channel Blockage	Operation	decrease heat transfer, possible corrosion issues	plant performance degradation, possible plant shut down, HX damage	visual/optical inspection	Yes	2	5	4	40	CB: Blockage of few water channels will not impact the performance and will not be detectable. HXs will have 1000's of water channels. Localized corrosion cause in blocked channel is a major concern.
OPS1-48	Heat Exchanger	Ammonia side blockage	Operation	decrease in heat transfer	plant performance degradation	thermodynamic values visual inspection	No	2	2	9	36	
OPS1-49	Heat Exchanger	Ammonia leak to ambient water	All	loss of ammonia	Environmental impacts, performance degradation	pH sensors, pressure	No	2	4	6	48	
OPS1-50	Heat Exchanger	Structural - mounts/flanges failing	All	heat exchanger damage, possible pipe and ductwork damage	plant shutdown and possible environmental damage due to ammonia	visual, vibration	Yes	2	8	5	80	

Failure Mode ID	Item Name	Failure Mode	Mission Phase/Op Mode	Failure Effects		Failure Detect Method	System Abort (SA) Failure	Criticality Analysis			RPN	Comments
				Local Effects	End Effects			Occ. Level (1-10)	Sev. Level (1-10)	Detect Level (1-10)		
OPS1-51	Heat Exchanger	Isolation mount failure	All	Galvanic corrosion of heat exchanger	plant performance degradation, possible plant shut down, HX damage	visual, vibration, electolytic	Yes	3	4	6	72	Should design so that the mounts are individually replacable
OPS1-52	Chlorination	Blockage	All	improper chlorination of some or all of the evaporator water channels	Biofouling/pitting corrosion causing decreased heat exchanger performance	pressures in chlorination system, thermo of OTEC, visual, chlorine sensors	Yes	5	3	5	75	
OPS1-53	Chlorination	System Failure	All	improper chlorination of all of the evaporator water channels	Biofouling/pitting corrosion causing decreased heat exchanger performance and possible ammonia leaks	pressures in chlorination system, thermo of OTEC, electrical, chlorine sensors	Yes	5	4	2	40	CB: I would increase the Occ level. This is liley to happen. In case of failure of chlorinaiton system, biofouling will reduce the tehrmal performance of evaporator by 20% to 30% in 10 to 15 days.
OPS1-54	Warm Water	Plastic Floating Through Screen (Stuck in Evaporator)	Operation	possible pitting and corrosion at site of plastic	Performance degradation, eventual heat exchanger damage	Visual	No	2	3	4	24	
OPS1-55	Warm Water	Screen Blockage, partial	Operation	decreased mass flow	performance degradation	pressure, flow sensors	No	7	2	2	28	
OPS1-56	Warm Water	Screen Breaking	Operation	no filter of water in heat exchanger	corrosion and blockage in heat exchanger leading to plant shutdown	Visaul	Yes	2	3	2	12	
OPS1-57	Cold water	Blockage/Obstructi on in ducting	Operation	decreased pressure and mass flow	performance degradation	pressure, mass flow, visual	Yes	2	4	2	16	
OPS1-58	CW Pipe Duct-Remora Interface	Leak/ Break	Operation	warm water in coldwater ducting	reduced performance, biofouling in condenser	temperature	No	2	2	3	12	
OPS1-59	Ammonia Pump	Bearing Failure	Operation	Bearings unable to function properly	Degradation of performance	Vibration, temperature	Yes	3	2	2	12	Redunant pump available
OPS1-60	Ammonia Pump Vessel	Mounting Failure	All	Pump or pipe damage	Ammonia leak, plant shut down	Visual, ammonia leaks	Yes	2	4	5	40	
OPS1-61	Ammonia Pump	Dry Pumping	Operation	Pump damage	Pump damage, switch pumps	Level Sensor, mass flow	Yes	2	2	2	8	Redunant pump available
OPS1-62	Ammonia Pump	Electrical Shorting	Operation	Pump damage	Pump damage, switch pumps	current	Yes	2	2	3	12	Redunant pump available
OPS1-63	Ammonia Pump	Particles in ammonia	Operation	Pump damage	Pump damage, switch pumps	vibration	No	2	2	2	8	Possible accoustic sensors? CB: Blockage of pump strainer due to welding particles left in the system should be clealry identified and necessary steps should be taken to clean the strainer.
OPS1-64	Ammonia Pump Sensor	Sensor Failures	Operation	Inaccurate commands	degradation of performance	Redundant sensor	No	2	3	2	12	Assumes redundant controls sensors
OPS1-65	Pump Pressure Vessel	Ammonia Leak in Vessel	All	Damage to electrical wires in vessel	Pump damage, switch pumps	ammonia sensor	Yes	2	2	3	12	Redunant pump available
OPS1-66	Pump Pressure Vessel	Vessel Failure	All	Pump damage	Pump damage, switch pumps	water detect	Yes	1	2	1	2	Redunant pump available

Failure Mode ID	Item Name	Failure Mode	Mission Phase/Op Mode	Failure Effects		Failure Detect Method	System Abort (SA) Failure	Criticality Analysis			RPN	Comments
				Local Effects	End Effects			Occ. Level (1-10)	Sev. Level (1-10)	Detect Level (1-10)		
OPS1-67	Pump Pressure Vessel	Water Leak	All	Pump damage	Pump damage, switch pumps	water detect	Yes	2	2	2	8	Redunant pump available
OPS1-68	Remora Structure	Leak/Puncture	All	Water in dry remora areas, loss of buoyancy	Plant shutdown, possible loss of remora and/or platform	water/flood detect	Yes	4	9	3	108	Need colllision bulkheads and campartments
OPS1-69	Valve	Particles in ammonia	Operation	Valve damage	possible Plant shutdown	pressure	Yes	1	4	3	12	
OPS1-70	Demister Valve	Failed Closed	Operation	Demister Overflow	Turbine Damage	Ammonia level measurement (in demister	Yes	2	4	2	16	Need to check with turbine vendor to see how much the turbine can handle
OPS1-71	Valve Actuation System	System Failure	Operation	Valve stuck in single location	Performance degradation, possible shutdown	Ammonia level measurement, pressure sensors	No	5	4	2	40	
OPS1-72	Communications to Land Failure	Fiber failure	All	On board personnel will operate plant, with no remote operators in loop	Communications will continue via wireless comms	Loss of comms	No	3	1	1	3	
OPS1-73	Communications to Land Failure	Wireless (sat/cell) failure	All	No wireless communications with the shore	Communications will continue via fiber	Loss of comms	No	4	1	1	4	
OPS1-74	Galvanic Effects	Corrosion	All	Pitting and damage to metal (HX, Structure, Pump, Pipes)	Damage to heat exchanger and other metal surfaces; heat exchanger damage results in reduced performance and possible ammonia leaks	Sacrificial anode with cameras, visual (divers), cathodic monitoring system	Yes	5	8	6	240	CB: This is najor design/operation issue. I am surprised that RPN is low. Occ. and Sev. Level should be increased.
OPS1-75	Ammonia Tank	Tank Sloshing	All	Added Stress on Tank walls	Effects on pumping; performance degredation; shortening pump life	Level Sensor	No	9	1	2	18	Need to add baffling to tanks
OPS1-59	Water Pump	Bearing Failure	Operation	Bearings unable to function properly	Degradation of performance, possible damage to other components	Vibration, temperature	Yes	3	6	2	36	
OPS1-60	Water Pump	Mounting Failure	All	Pump or pipe damage	Ammonia leak, plant shut down	vibration, strain	Yes	1	6	5	30	
OPS1-62	Water Pump	Electrical Shorting	Operation	Pump damage	Plant shutdown	current	Yes	2	6	3	36	
OPS1-64	Water Pump Sensor	Sensor Failures	Operation	Inaccurate commands	degradation of performance	Redundant sensor	No	2	3	2	12	Assumes redundant controls sensors

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-39
OCEES OTEC Water Study – 10 September 2010
OTEC-2010-001

17 September 2010

Prepared for:

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OTEC WATER PRODUCTION AND DELIVERY TRADE STUDY

Prime Contract No.: NAVFAC OTEC Project N62583-09-C-0083

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EXECUTIVE SUMMARY

- Reverse osmosis (RO) determined best desalination process for OTEC integration
- Land-based RO system deemed most cost-effective
- Not economically competitive in current US markets

OCEES International, Inc. has performed a trade study of seawater desalination technologies for use with ocean thermal energy conversion (OTEC) power production. The study was conducted in order to determine the best option for producing potable water from seawater in conjunction with a platform mounted OTEC facility. Various scenarios were analyzed to account for multiple production capacities, site locations and production and delivery methods.

Potable water is an increasingly scarce resource in many parts of the world, particularly in highly populated coastal areas where the demand for potable water is high. OTEC facilities, being near coastal regions by their very nature, offer unique synergies for coupling with desalination plants. OTEC power production requires substantial flows of both warm and cold seawater. These flows offer benefits of different types for different desalination technologies. The nature of OTEC allows for combining power production with both thermal and membrane desalination processes.

A basis of design was created to provide a consistent means of comparing the desalination processes considered in the analyses performed in this study. The design basis took into account parameters such as flow rates, temperatures, energy requirements and plant location. Of particular importance regarding the outcome of this study is the economic analysis. Several key parameters were given assumed values based on the current economic climate. The economic analyses were performed for only one desalination technology, but there were two production capacities considered and both assume the same economic parameters.

The first step in determining the most favorable seawater desalination processes for combining with OTEC was an extensive literature review of the technologies available. During the literature review many possible alternatives were examined and the basic fundamentals of each were noted. Based on how each alternative works, a few were selected as being suitable for commercial use with an OTEC facility. The following requirements were matched against each desalination process to determine which were potential matches for integration with OTEC:

- Capable of producing up to 50 MGD
- Commercially proven and reliable
- Capable of producing potable water within WHO and USEPA standards
- Minimum disruption of energy production (require the least amount of electricity on a per unit production basis and consume the least amount of water / thermal resources prior to OTEC electricity production)
- Produce potable water in a cost-effective manner
- Compliant with all applicable environmental regulations
- Meet any applicable building codes or ABS requirements
- Minimize plant footprint on the platform as much as possible
- Maintenance requirements practical for a commercial operation on an offshore floating platform

Based on these requirements there were three processes chosen to be evaluated: multi-stage flash distillation, multiple effect distillation and reverse osmosis. Reverse osmosis was evaluated for both cold seawater and warm seawater desalination.

The evaluation procedure used is the weighted summation method of multi-criteria decision analysis. The analysis compares seven factors of the four desalination processes under consideration. Each of

the factors is weighted according to its importance relative to the specific application, i.e. – a given capacity of water production in conjunction with a platform-based OTEC facility. The factors examined in this analysis are:

- Specific capital cost
- Operation and maintenance cost
- Space requirements
- Environmental considerations
- Product quality
- Cold seawater consumption
- Energy consumption

The result of the evaluation shows reverse osmosis with warm seawater is the most favorable desalination method for use with a floating platform OTEC system. Reverse osmosis with cold seawater received the second highest score followed by multiple effect distillation and multi-stage flash. The amount of cold seawater consumption is particularly damaging to the multi-stage flash and multiple effect distillation processes. The design of the particular OTEC system for this evaluation, and consistent with current Lockheed Martin OTEC platform design, requires the cold seawater used in the desalination process be drawn away from the OTEC system prior to power production. This causes a major decrease in the power production capability of the system. The results of this evaluation are specific to the scenario outlined by the basis of design and the particular OTEC system involved, and are not applicable to all OTEC systems. A new evaluation would need to be conducted for any variation in the alternatives considered.

While the OTEC facility is limited to an offshore platform in this study, the reverse osmosis seawater desalination system can be considered for both platform-mounted and shore-based operation with requisite energy cabled to shore from the OTEC facility. If the reverse osmosis system were located on the platform, there would be need to deliver the potable water to shore. Four different possibilities for water delivery are examined including water bags, barges, tankers and pipelines. The water bags option is not considered to be commercially suitable at this time. They have been used for commercial operations in the past, but fell out of favor due to problems with breakage. Each of the other delivery methods added excessive cost to the water production. The costs are not necessarily prohibitive in all cases, but in general they do not compare well with the costs of water production for a land-based system.

An economic analysis was performed for the various scenarios involving the chosen seawater desalination method (reverse osmosis). First year sale prices were varied so that IRR and ROI data could be compared over a 25 year project life for 1 MGD and 50 MGD capacity plants, both onshore and offshore. The land-based systems have considerably higher returns than their platform-based counterparts. This is due to the high cost of space on the platform and the high cost of delivery for the product water.

Even for the particular platform-based OTEC system considered in this study, the best choice for a coupled desalination process would be very site specific and condition dependant. The same is true for the economics of the chosen system. Generalizations made regarding the desalination of seawater in conjunction with OTEC power production should be done so with a cautious approach. In all cases examined, the cost of producing potable water from OTEC powered seawater desalination is not competitive in any current U.S. market. It is competitive in some foreign markets and could become so in the U.S. as demand and price grow in certain regions.

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1 NEED FOR SEAWATER DESALINATION

- Only 0.5% of freshwater in the world is easily accessible
- 44% of world's inhabitants live within 150 km of the coast
- Populated areas struck by natural disasters need water quickly

The scarcity of potable water is a growing problem worldwide, particularly in arid regions and among developing countries. Compounding this problem is the growing contamination of freshwater sources, which only comprise about 2.5% of all water on Earth to begin with. Of that, only 0.5% of the total available is found in easily accessible sources such as lakes, rivers and aquifers. The rest is frozen in glaciers. The remaining 97.5% is seawater. Freshwater contains up to 1,500 ppm in total dissolved solids (TDS). Seawater ranges from 10,000 – 45,000 ppm, with 35,000 being the standard reference [15]. The United States Environmental Protection Agency recommends an upper limit of 500 ppm for drinking water.

In the United States people consume on average up to 400 L of freshwater per day and in other western countries the consumption level reaches only 150 L per day. Some countries in Africa have consumption rates of only 20 L per day, which is at the World Health Organization recommended limit for individual survival. When considering infrastructure and communal needs such as those of schools and hospitals, the necessary level is more than doubled to 50 L per person per day. With the rising population, industrialization of developing nations and overall increase in quality of life throughout most parts of the world, freshwater consumption levels continue to rise. It is estimated that by the year 2040 demand for freshwater will surpass the available supply.

According to the United Nations Atlas of the Oceans, more than 44% of the world's inhabitants live within 150 kilometers of the coast. This is more people than there were in the entire world just 60 years ago. In the United States, 53% of the population lives near the coast. In another 30 years it is estimated that over 70% of the population will be coastal. The crowding of the population in a certain area leads to overexploitation of regional resources including fresh water. Given the number of people within access of the coast and the sea, it is naturally advantageous to turn to the sea for fresh water.

Populated areas struck by natural disasters are faced with a great need to quickly supply potable water to the victims for drinking, cooking and sanitation purposes. In industrialized nations the freshwater infrastructure normally relied on is often damaged or contaminated to the point that it can't be used in the immediate recovery period after the devastation of such an event. In developing nations the infrastructure might not be there at all, making the acquisition and distribution of potable water all the more difficult.

Over 75% of the world's desalinated water capacity is used by the Middle East and North Africa according to the USGS. The United States is one of the most important industrialized countries in terms of desalinated water consumption at about 6.5%. California and Florida are the major consumers of desalinated water in the US.

2 IMPORTANCE OF WATER PRODUCTION IN ASSOCIATION WITH OTEC

- Desalination of seawater is energy intensive
- OTEC offers unique symbiosis of power and water production
- OTEC offers environmental benefits over traditional desalination drivers

Desalination of seawater requires a significant amount of energy regardless of the technique used. There are several renewable energy (RE) technologies currently being used to power desalination processes. **Error! Reference source not found.** shows what relationships between various RE sources and the desalination processes reviewed in this study work best. Some of these relationships are in commercial operation today; others have yet to be demonstrated. Solar and wind are proven RE sources that can provide electricity to any electrically driven desalination system. This is true for all renewable energy sources, but solar and wind are currently the most commercially demonstrated. Tidal and wave energy have very recently begun to show much promise, but are still in early phases of commercialization. While all RE sources are rather site dependant, this is much more so the case for geothermal. Geothermal sources offer the benefit of access to both electricity and heat, which allows for the ability to couple this resource with a wider range of desalination processes.

Ocean thermal energy conversion (OTEC) also offers unique opportunities for symbiosis of power production and seawater desalination. Massive amounts of seawater are pumped through an OTEC system in order to generate power. Additionally, OTEC requires access to both a heat source and a heat sink. While the temperature differential is not as great as is found in geothermal, hot and cold water can be used along with vent compression to allow OTEC to function with typical thermal desalination processes as well as those driven solely by electricity.

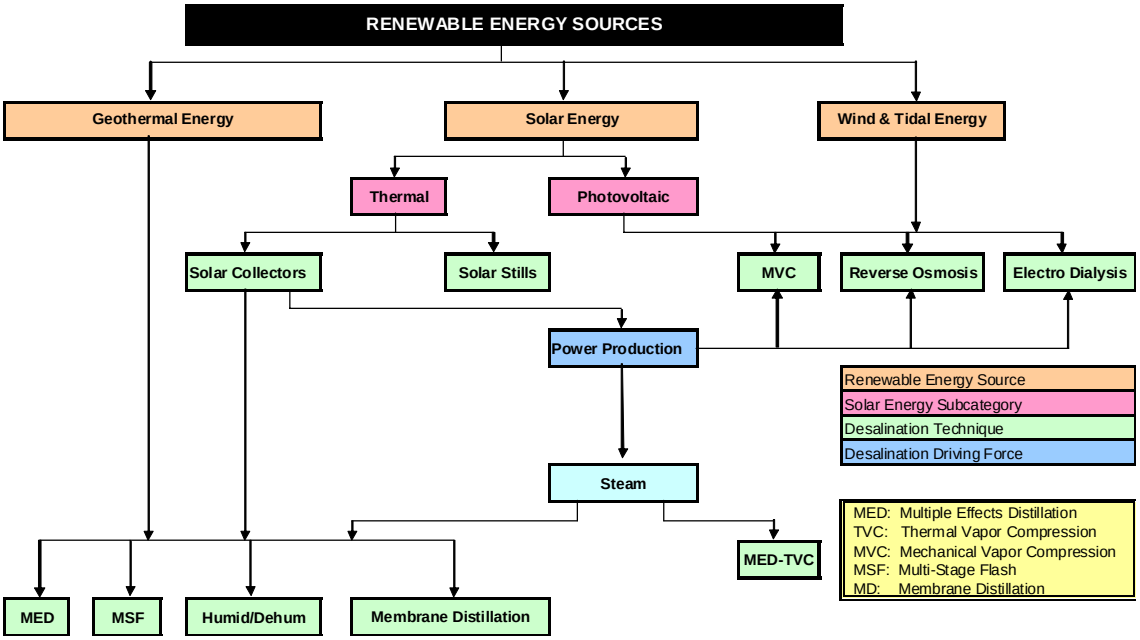


Figure 2-1 Flow Chart for Combining Renewable Energy with Water Desalination

With the growing need for potable water, the lack of available fresh water sources from which to retrieve it, the extremely high coastal populations and rising energy prices, pairing potable water production with renewable energy from the sea is a natural fit. As OTEC already requires the pumping of mass quantities of seawater there is an inherent cost savings and environmental impact mitigation inherent to the desalination process when using OTEC as the power source.

The environmental impact of desalinating seawater is quite high when using fossil fuels to supply the massive quantities of energy needed. Replacing the energy supply with a renewable energy source such as OTEC eliminates the pollution caused by fossil fuels and other problems associated with the use of fossil fuels to produce potable water. Greater self-sufficiency is achieved through the use of a readily available source of energy like OTEC rather than relying on fossil fuels such as oil that are largely imported from often unstable or unfriendly countries. Obtaining the limited supply of domestic fossil fuels poses problems as well whether it be mining for coal or drilling for oil. Recent incidents involving both the coal and oil industries in the US have resulted in great personal, environmental and financial tragedies. Explosions in coal mines and on oil rigs and other similar catastrophes are not a problem in OTEC systems due to the very nature of the power production cycles. The rise in fossil fuel prices and the expected decline in OTEC prices as the technology develops also make the coupling of seawater desalination and OTEC power production attractive.

3 BASIS OF DESIGN

- Design feedwater temperatures established
- Production design levels: 1 MGD; 50 MGD
- Follow National EPA Primary and Secondary drinking water standards

The water production and delivery trade study is based on a set of parameters determined by the overall OTEC system design, the needs of the stakeholders, and the technical and economic practicalities of the available technologies. Multiple options are explored including onshore and offshore water production and high and low production levels. The parameters used to define the basis of design include:

- Feedwater temperatures
- Flow rates
- Production levels
- Source of feedwater
- Location of production facility
- Water quality parameters
- Regulations and design code

These parameters vary depending on the option being considered. For example, flow rates change depending on production levels, but water quality parameters remain the same. Other parameters vary depending on the location of the production facility – onshore or offshore.

3.1 Feedwater Temperatures

Feedwater temperatures are based on the OTEC system design parameters, the location of the water production system and the type of water production technology being considered. Onshore production facilities will use warm surface water as the feedwater. For this OTEC platform design proposed by Lockheed, offshore production facilities will use supply cold water direct from the OTEC process cold water pipe (CWP) or warm surface water. Depending on the technology used there are certain pros and cons associated with the two different sources. Higher temperatures aid in the efficiency of the desalination process, but the warm surface water of the ocean contains more biological matter which will likely impose the need for a pre-filtration system. Colder temperatures decrease the efficiency of the desalination process, but have very little biological matter. The trade offs here were considered for the various technologies individually.

The temperatures being considered during this study are obtained from the OTEC power system design parameters as follows:

Warm surface water inlet temperature: 25.7°C
Cold deep ocean water effluent temperature: 7.86°C
Cold deep ocean water inlet temperature: 4.1°C

The warm inlet water and the cold deep water inlet are sources for desalination under current Lockheed Martin OTEC platform design and considered in this analysis. The cold inlet water also represents a potential source of condenser water for certain desalination processes such as flash evaporation or multiple effect distillation.

3.2 Source of Feedwater

The feedwater source will vary depending on location of the water production system (onshore or offshore) and the type of technology being used. A land-based water production system would use surface water as its feed source as pumping the cold deep ocean water to shore for this purpose would not be warranted for practical and economical reasons. An offshore water production system might use either warm surface water or cold deep ocean water depending on the cost benefit analysis of using either source for any given water production technology.

3.3 Production Levels and Flow Rates

Two production levels of desalinated water were examined during the trade study: 1 MGD and 50 MGD. There are also two OTEC system production levels being considered: 10 MW and 100 MW. Flow rates for the water production system are dictated by the chosen desalination technology and the desired production level. Some desalination technologies such as reverse osmosis require a small enough flow rate at either water production level being examined that both a 10 MW OTEC system and a 100 MW OTEC system can easily supply the necessary amount of feedwater. Other desalination technologies requiring higher feedwater flow rates have limited production levels at the 10 MW power output scale.

3.4 Location of Production Facility

Two potential locations for the water production facility are under consideration: onshore and platform-mounted offshore. The location of the facility will play a major role in determining the desalination technology used and the delivery system for the water produced. For onshore systems specific consideration regarding the desalination technology is given to the source of the feedwater and potential contaminants, footprint of the system, effluent discharge impacts and concerns, desired production level, and feedwater temperature. Delivery methods for onshore water production considered include direct piping to local distribution systems or the use of storage tanks and delivery trucks. Important factors when considering a platform-based system include volume and weight of the system, stability of the platform, desired production level and available feedwater flow rates. Delivery methods for offshore water production considered include transfer pipelines to the shore, transport bags, tankers and barges that could carry the water to shore. From there it could be pumped directly into the local distribution system or offloaded to trucks for transport.

3.5 Water Quality Parameters

Most desalination systems commercially available in the United States will meet State and Federal water quality standards. Each technology analyzed in this study was evaluated against those standards. The primary drinking water regulations are those that must be adhered to by law. The secondary drinking water regulations are non-enforceable guidelines that may impact cosmetic or aesthetic effects of product water. They are recommended but not mandated by the EPA. Some states might choose to adopt them as enforceable standards. There are six categories of contaminants covered by the regulations: Disinfectant, Disinfection Byproduct, Organic Chemicals, Inorganic Chemicals, Microorganisms and Radionuclides. In an open ocean setting, as would be found for an offshore system, many of these contaminants are unlikely to be found, but would still have to be monitored. For a land-based water production system, some of these contaminants might be more likely to pose a threat depending on the specific area of the feedwater intake.

Depending on the likelihood of encountering these various contaminants, certain desalination techniques might be preferable over others. The National Primary and Secondary Drinking Water Regulations of the USEPA will be met by the desalinated seawater regardless of the technique chosen.

3.6 Regulations and Design Code

The desalination system will have to conform to applicable regulations and design codes for the location where it is being installed. Local building codes will need to be followed and permits will need to be obtained for land-based systems. For platform-based systems conformation with American Bureau of Shipping (ABS) and other applicable standards is necessary. Because design efforts were not included in this analysis, further consideration of the ABS standards was not included in this review.

3.7 Desalination Technologies

Several desalination technologies were explored during the trade study. Thermal processes, mechanical processes, chemical processes and hybrids of the three comprise the technologies available for desalination of seawater. Multi-stage flash distillation (MSF) and multiple effect distillation (MED) are the most common technologies currently in use. However, due to the successful development of energy recovery systems, most new commercial desalination systems use reverse osmosis (RO) technology. MSF and MED represent thermal processes, while RO is a mechanical process. Chemical processes are typically restricted to brackish water desalination projects and are not typically suitable for desalination of seawater. Hybrid processes utilize characteristics of multiple desalination techniques.

Thermal processes affect a phase change (typically evaporation/vaporization) to separate fresh water from seawater, and then collect the fresh water product (typically condensate). These systems are usually energy intensive. Thermal desalination processes include multi-stage flash distillation (MSF), multiple effect distillation (MED), freeze distillation and solar distillation. Mechanical processes separate the dissolved solids from the water. These processes include vapor compression, reverse osmosis (RO) and electrodialysis. The chemical process of ion exchange is not used to desalinate seawater, but can be used to further purify water after desalination when very low levels of dissolved solids are necessary. Such is the case for water used in hydrogen production.

4 DESALINATION TECHNOLOGIES OVERVIEW

- Major categories consist of membrane processes and thermal processes
- Thermal processes can be modified to run solely on electricity and OTEC temperature differential
- Major membrane resource is RO

There are two major separation categories that are examined in this study: membrane separation processes and thermal separation processes. Each category has multiple processes associated with it and one process, membrane distillation employs aspects of both categories. The groupings of the two categories are shown in Figure 4-1.

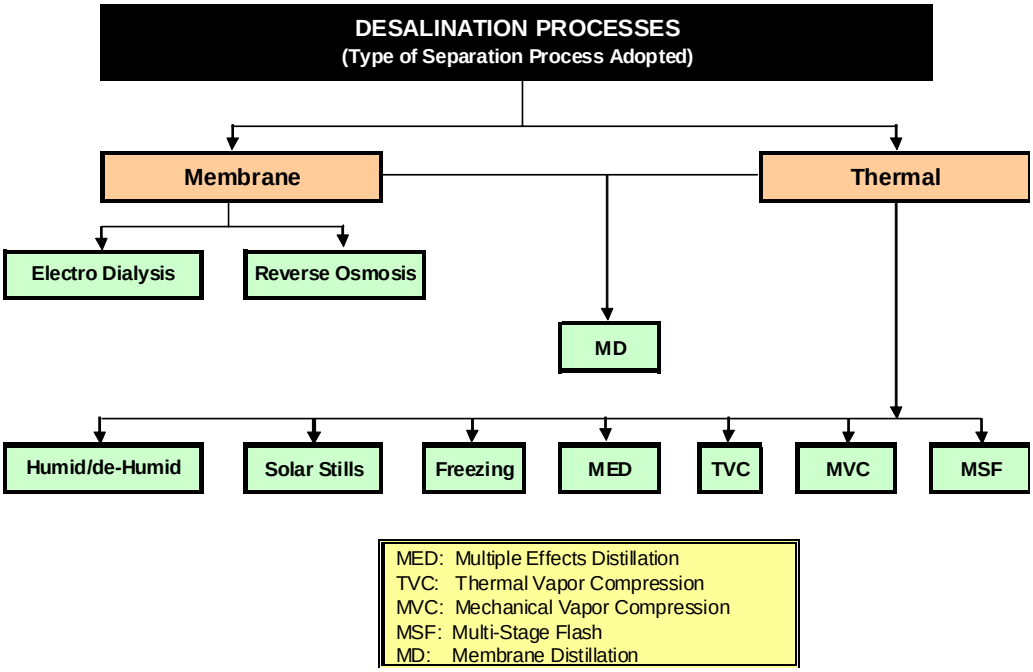


Figure 4-1 Desalination Processes Grouped by Type of Separation Process

Each desalination process is at a particular level of commercial viability ranging from concept to having been commercially proven. This section will describe each technology and identify its technology readiness level (TRL). The TRLs are defined by the Department of Defense in the Technology Readiness Assessment Deskbook, July 2009 as:

- TRL 1: Basic principles observed and reported
- TRL 2: Technology concept and/or application formulated
- TRL 3: Analytical and experimental critical function and/or characteristic proof of concept
- TRL 4: Component and/or breadboard validation in a laboratory environment
- TRL 5: Component and/or breadboard validation in a relevant environment
- TRL 6: System/subsystem model or prototype demonstration in a relevant environment
- TRL 7: System prototype demonstration in an operational environment
- TRL 8: Actual system completed and qualified through test and demonstration
- TRL 9: Actual system proven through successful mission operations

4.1 Thermal Processes

Thermal processes account for the majority of commercial seawater desalination facilities across the globe with multi-stage flash distillation comprising the bulk of these desalination plants. The oldest and second most common thermal process is multiple-effect distillation.

4.1.1 Multi-stage flash distillation (MSF)

In multi-stage flash distillation freshwater is formed from condensing steam generated in heat exchangers in multiple stages. The MSF process accounts for about 40% of all seawater desalination plants in commercial operation. The process consumes a fair amount more energy than the reverse osmosis (RO) process, but its reliability has made it commercially competitive with RO. The system itself is made up of a brine heater, flashing stages, a vacuum ejector, chemical addition pumps and feed screens. The seawater is initially heated in a heat exchanger called a brine heater by means of condensing steam on one side of the heat exchanger with seawater flowing on the other side. The heated seawater is then sent to a second vessel (multiple stage heat exchanger) of lower pressure forcing the flash evaporation of seawater. The seawater continues through the stages of the second vessel with each stage being of a lower pressure than the previous, resulting in further flashing until the seawater has lost too much heat such that it is no longer efficient to reduce the pressure below the saturation temperature of the seawater. The result is a decrease in brine temperature but an increase in salinity through each stage of the process. The vapor then passes through a vent line and demister, into a chamber with tube bundles filled with the incoming seawater. This process causes the vapor to condense so it can be collected as fresh water. A schematic of the MSF process is shown in Figure 4-2.

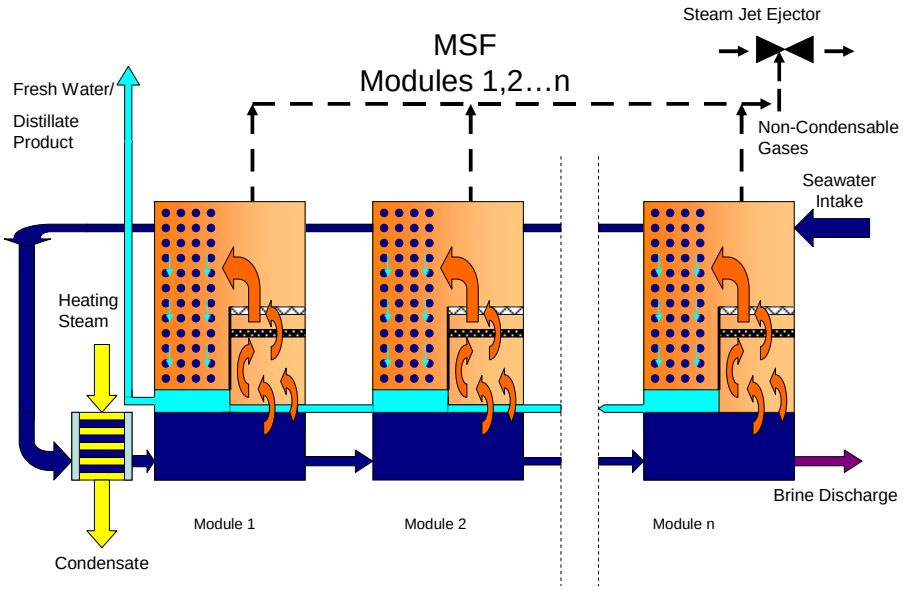


Figure 4-2 MSF Schematic Drawing

The feed seawater passes in counterflow to the distillate and the brine waste as it is heated up on its way to the brine heater. This helps reduce heat loss by heating up the seawater on its way to the brine heater. It is very important that the seawater undergoes deaeration in the MSF brine circulation system. If these gases were not to be removed, they would be released in the flashing stages and reduce the heat transfer rate due to low thermal conductivity. The gases could also be a factor in causing corrosion at various points in the system. MSF can be integrated with other desalination technologies such as thermal vapor compression, mechanical vapor compression, and vent compression. Multi-stage flash seawater desalination has a TRL of 9 and has been operating at capacities of at least 50 MGD for an extended time.

When MSF is integrated into an OTEC system, vent compression (vacuum) must be utilized to desalinate the water at the warm surface seawater temperature since a high-heat thermal energy source is not available as is the most common usage of this technology in commercial desalination facilities. MSF with vent compression (MSF-VC) cycles warm water feed water through each stage and module. The water is drawn through by vacuum conditions provided by the vent compression exhausts. These exhausts suck vapor towards condensing pipes through which the cool seawater flows. The vapor condenses and falls into collecting pools, which are then piped away as fresh water. The cold seawater and warm seawater flow in opposite directions in order to produce higher differences in temperature at each stage. The brine of the warm seawater as well as the cold seawater discharges are mixed before being ejected back into the water to reduce the brine's salinity and increase the cold water's temperature to minimize environmental impact. A schematic of the MSF-VC process is shown in Figure 4-3. Multi-stage flash with vent compression seawater desalination is at a TRL of 7. This technology has been demonstrated by the National Institute of Ocean Technology in India with a prototype in an at sea environment.

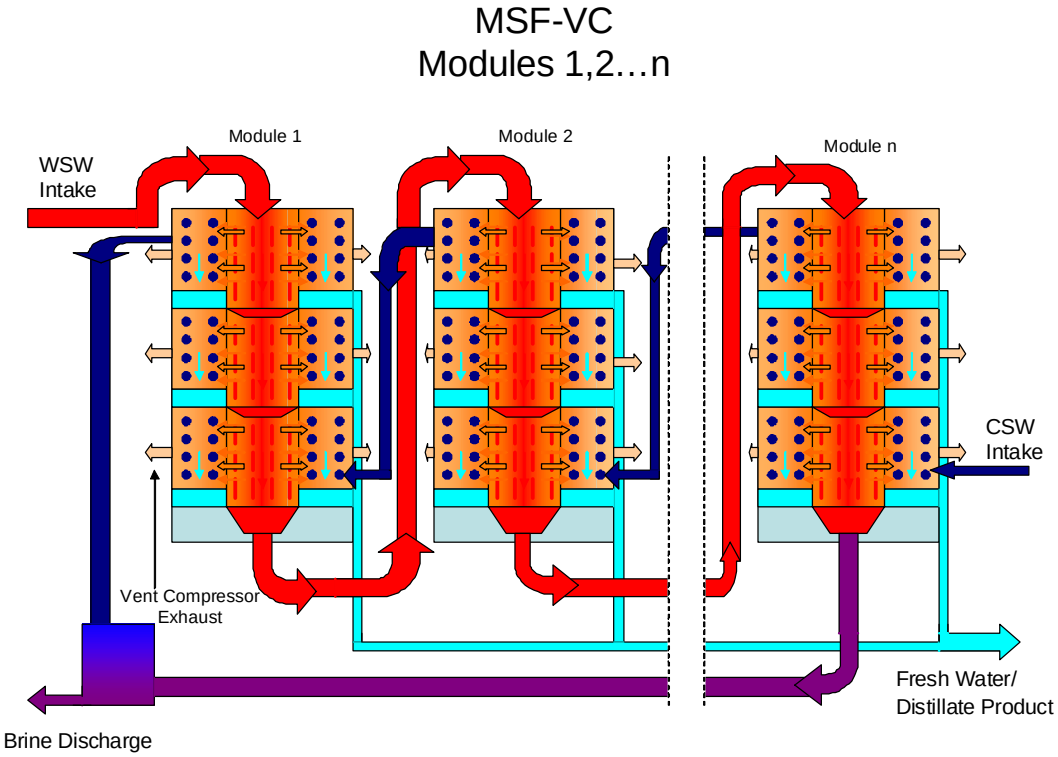


Figure 4-3 MSF with Vent Compression Schematic Diagram

4.1.2 Multiple-effect distillation (MED)

Multiple-effect distillation is the oldest large-scale commercial desalination process. This technique involves the use of a series of evaporators with a progressively reduced pressure in each evaporator, or effect. Seawater is heated to boiling in the first effect by being sprayed onto multiple evaporator tubes heated by steam from an external source (typically a thermal power plant waste steam). The MED process is typically configured in conjunction with a power plant or other source of waste heat to exploit this high energy resource. The condensed steam is recycled to the power plant and the evaporate from the seawater is sent to the subsequent effects to heat the seawater that was not evaporated in the first effect. In the second and following effects, some of the evaporated seawater comes off as the distillate as it is condensed and some of the evaporated seawater is sent to the next effect to heat the seawater feed to that effect. The process continues with each effect having a lower temperature and pressure. The water that is not evaporated in the respective effect pools at the bottom and is collected as brine discharge. The vapor from the last effect moves back to the seawater intake pipe where it condenses to be taken away as fresh water. Similar to MSF, each of the effects are under vacuum conditions where various non-condensable gases are desorbed and vented from the chambers and ejected. This MED process can additionally utilize mechanical vapor compression, thermal vapor compression, or vent compression to achieve the necessary pressures and temperatures for desalination. Figure 4-4 shows a schematic diagram of a typical MED process. The multiple-effect distillation process has a TRL of 9 as it has been demonstrated commercially for many years.

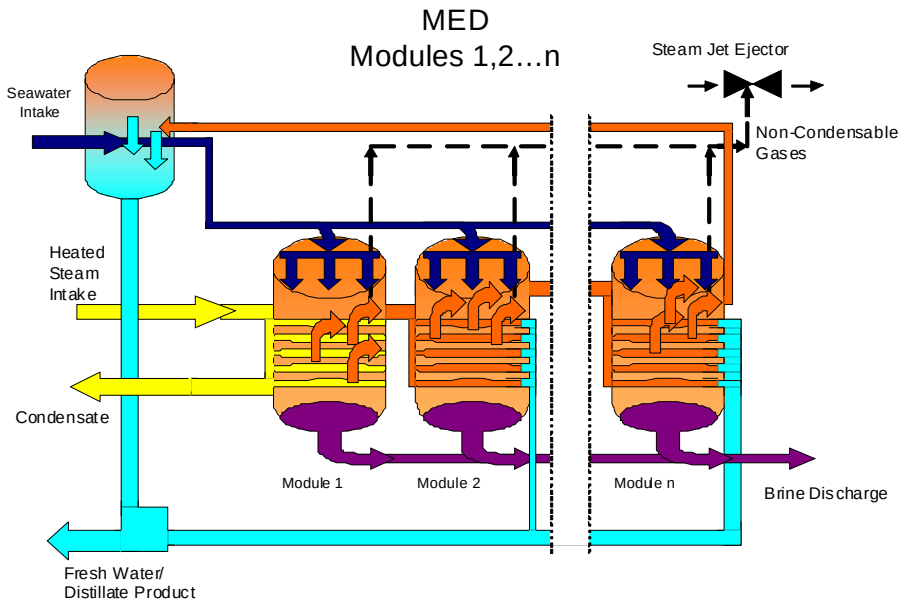


Figure 4-4 MED Schematic Diagram

In the OTEC process, there is no excess steam to provide the “free” energy required to affect the phase change necessary for thermal distillation of the seawater. Therefore, similar to MSF, when MED is integrated with OTEC, it too uses vent compression technology (MED-VC) in order to lower the vapor pressure above the seawater effectively distilling the water utilizing only electricity and warm and cold seawater in the process. The warm water enters the plant and is flash evaporated. This

vapor is then drawn into multiple modules where it is condensed by the cold seawater being pumped through condensing pipes. Any excess vapor that fails to condense is passed onto the next effect within the module. The cold water in the pipes is drawn in from deep ocean water and after passing through each effect, is mixed with the discharge brine from the warm water flash tank. The mixed effluent is then discharged into the ocean with minimal environmental effects. A schematic of the MED-VC process is shown in Figure 4-5. Multiple-effect distillation with vent compression has a TRL of 2. The technological concept has been formulated, but physical laboratory studies have not been initiated.

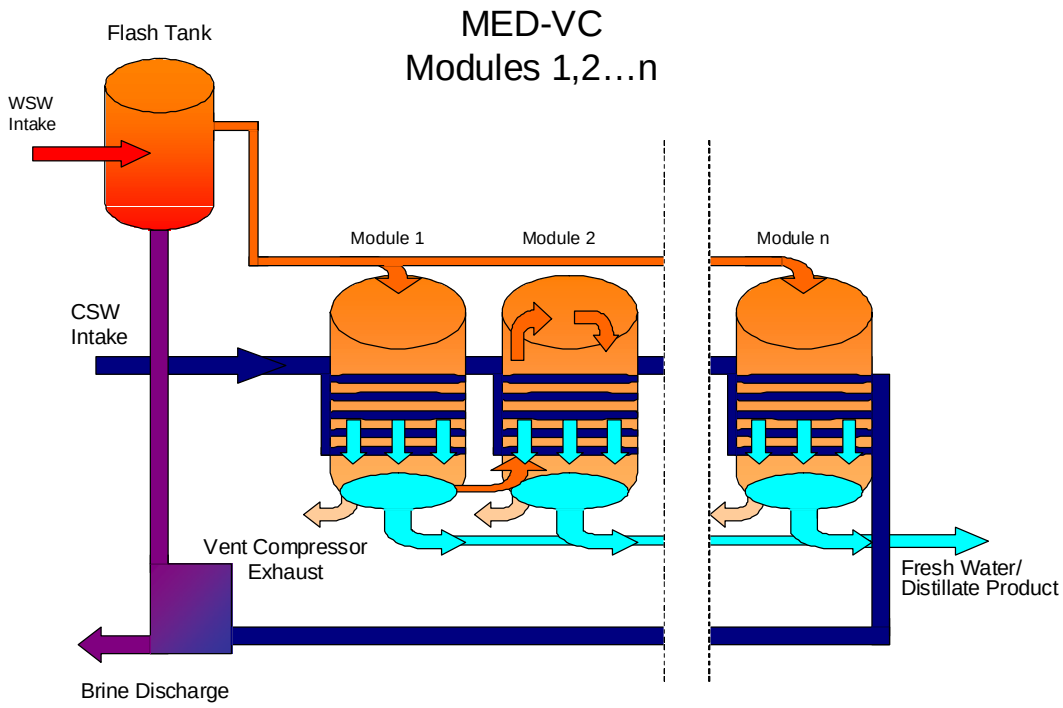


Figure 4-5 MED with Vent Compression Schematic Diagram

4.1.3 Thermal Vapor Compression (TVC)

Thermal Vapor Compression is very similar to MED. The main difference is the reuse of the energy of the vapor produced in the last effect. Thermal vapor compression uses a steam ejector to compress part of the vapor that is formed in the last effect. The compression increases the temperature higher than the temperature of the vapor generated in the first effect. The vapor from the last effect is then used as a heat source for the first effect. Thermal vapor compression has a TRL of 9 as it is currently being used successfully at low production capacities.

4.1.4 Mechanical Vapor Compression (MVC)

Mechanical Vapor Compression was developed as a purely electrically driven thermal process. The main difference between MVC and TVC is that MVC processes do not use a steam jet ejector but rather use a mechanical compressor to compress the entire vapor from the final effect. The mechanical compressor is more efficient than the steam jet ejector, but it is also more costly and requires more maintenance due to its additional moving parts and complexity. MVC systems also utilize the outlet brine in a heat exchanger with the feed stream as a system of preheating the water.

Mechanical Vapor Compression is the only other seawater desalination technology other than Reverse Osmosis that does not utilize a thermal resource, but runs solely on electricity. Mechanical vapor compression has a TRL of 9, but like thermal vapor compression, is only used for low production capacities as a stand-alone process.

4.1.5 Solar Stills

Solar Stills are a form of desalination that utilizes solar energy in its thermal processes. The most basic design for a solar still is a single-basin type. The basin is air tight and covered with a transparent material such as glass, with the interior surface blackened in order to absorb the most solar energy possible. The salt water that is trapped in this basin heats up and evaporates from the basin, condensing on the inside of the glass cover and trickling down the slanted glass to a section that collects the distillate. There are designs that utilize multiple effects that contain parallel plates with air gaps in between. The evaporate produced from the first effect gives off some of its energy to heat the next plate. This type of desalination plant requires, however, a lot of sunlight and is not efficient commercially at large scales. Solar stills have a TRL of 9, but are not practical for large-scale production.

4.1.6 Solar Collectors

Solar Collectors are devices that absorb incoming solar radiation, and, after converting it to heat, relay the energy to a flowing stream of water. The primary types of devices developed for solar collection are principally stationary systems such as solar ponds, single-axis tracking devices, and two-axis tracking devices. The flowing water is generally used as a preheater for an MED or MSF system that is connected to the solar heat collector. The water heated by the collector bank specifically flows to a heat accumulator which then flows through the first of the heating tubes in the MED evaporator or the first stage of the MSF process. Solar collectors have a TRL of 9, but are not practical for large-scale OTEC driven seawater desalination.

4.1.7 Humidification-Dehumidification

Humidification-dehumidification is a desalination process that utilizes the power of solar energy. The system consists of a condenser unit, an air/water humidifier, a cooling water pump and a hot water pump. The process starts by humidifying and heating the ambient air with hot water coming from a solar collector. This air is then dehumidified in a large surface condenser that utilizes the seawater feed, creating a convection cell. The feed is preheated by using the latent heat of condensation. This process has the potential to be utilized on a small scale and can operate at low temperatures using sustainable energy sources. Seawater desalination through humidification-dehumidification has a TRL of 4. The basic components have been demonstrated in a laboratory environment.

4.1.8 Vacuum freeze desalination (VFD)

Vacuum freeze desalination is a thermal desalination process that freezes the seawater instead of vaporizing to affect the phase change required for the separation process. As the saline water freezes, the salts are left behind as the ice forms. The system runs at lower temperatures and in low pressure vacuum chambers. Some of the water flashes off as vapor, removing heat and allowing ice to form. The ice is then washed with fresh water and runs off into other parts of the system. Although the energy requirement is less than other thermal processes, the technology has yet to be

commercialized due to issues with salt carry over in the product water. Vacuum freeze desalination has a TRL of 7. It has been demonstrated in a relevant environment, but not for large capacity seawater desalination.

4.1.9 Membrane Distillation (MD)

Membrane Distillation is a process that brings together a thermally driven distillation process with a membrane separation process. The hydrophobic membranes in this process prevent liquid from entering the pores while allowing water in the vapor phase to go through. The main force that drives the vapor through the membrane is a pressure differential due to a temperature gradient between the hot feed stream in the evaporator and a cooled permeate stream. There are multiple ways that these channels can be set up technically. Location of the vapor condensation can vary from a cool plate separated by the membrane to a location outside the membrane module altogether, pumped out via a vacuum pump. MD is not operational commercially in desalination plants today, but has advantages for small plants where a low temperature waste heat or solar thermal heat source is available. Membrane distillation has a TRL of 9, but it is in the early stages of commercialization and only used for small scale application.

4.2 Membrane Processes

There are two basic types of membrane processes. Those that extract water have semi-permeable membranes that allow the water to pass through without the salt and create two separate streams: a permeate (product water) and a concentrated brine discharge stream. This is the case for reverse osmosis, one of the most rapidly developing desalination technologies of the last couple of decades. Another membrane process uses ionic exchange membranes to draw the salts out, leaving fresh water behind. This technology is represented by electrodialysis and ion exchange desalination. Neither of these is used for seawater desalination, but are utilized as brackish water desalination technologies. The higher salt content of the seawater drastically reduces the membrane and process efficiency in these technologies.

4.2.1 Reverse Osmosis (RO)

Reverse Osmosis is a desalination process that forces seawater through membranes that do not allow the salts nor nearly any dissolved matter to pass. By applying a pressure differential across the membrane, the water is forced to move through it. The seawater is pre-treated to remove large debris and suspended solids. Chemicals may also be added during the pre-treatment process to fight bio-fouling within the membrane modules. After it has been pre-treated, the seawater is pumped through the membrane module. This segment of the process requires the bulk of the energy expended. There are two streams exiting the membrane module. The concentrated brine stream, which does not pass through the membrane, is rejected back to the sea. Upon its discharge the brine passes through an energy recovery system providing a significant energy savings by “recovering” a substantial portion of the energy input to create the high pressure differential required to force the water through the membrane. The desalinated permeate is sent on to a post-treatment segment for disinfection, pH adjustment and the removal of any dissolved gases. Reverse Osmosis has been determined by the EPA to be the best desalination technology for removing harmful compounds such as arsenic, barium and nitrate [28]. A schematic of a seawater reverse osmosis plant is shown in Figure 4-6.

Reverse Osmosis has become one of the most popular and economically attractive desalination technologies available. Its low energy requirements, environment-compatibility, and high efficiency all

are benefits that coincide with membrane technology. However, RO plants require very detailed pretreatment of the water in order to prevent damage to the system membranes, which are very sensitive to external influences. Although similar pretreatments, such as chlorine and anti-scalants used in RO plants are also used in other types of desalination plants, RO plants require additional treatments throughout the process. One such example is that the chlorine that is injected to mitigate biofouling of the system has to be neutralized before passing through the RO stage to avoid oxidation damage to the membranes by residual chlorine in the feedwater. The removal of suspended solids is also a step unique to membrane processes, as thermal processes are not typically adversely affected by system clogging or other complications associated with membrane technologies. Reverse osmosis has a TRL of 9. It is commonly used in large-scale commercial operations.

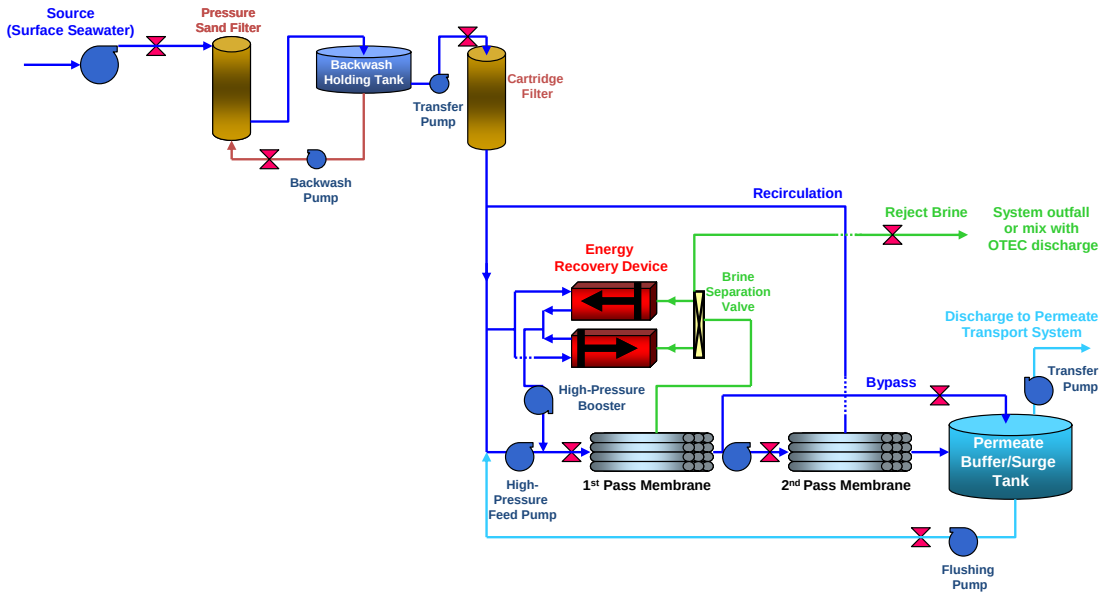


Figure 4-6 Seawater Reverse Osmosis Schematic Diagram

4.2.2 Electrodialysis (ED)

Electrodialysis uses stacks of positively and negatively charged membranes to separate salt ions from water. There are three streams in the electrodialysis process. The concentrate stream, diluate stream and electrode stream flow through their corresponding compartments created by the membranes. An electric potential difference across the stacks creates the diluted stream as brackish or seawater is fed through the system. Negatively charged ions such as chloride are drawn through an anion exchange membrane towards an anode into a concentrate stream. A negatively charged membrane prevents them from traveling beyond. In a similar fashion, the positive ions are drawn to a cathode through a negatively charged membrane. In this manner, the concentrate stream gains in ion concentration as the diluate stream becomes more and more diluted resulting in the desalinated product water. The electrode stream flows next to the electrodes containing a solution that will react in a manner to carry ions into the concentrate stream or attract ions from the diluate stream. This creates a current traveling across the stack while maintaining neutral solutions.

Electrodialysis has a TRL of 9, but is not appropriate for seawater desalination. Electrodialysis is not suitable for seawater because the salinity is too great. However, it could be used to further purify

desalinated seawater for purposes requiring ultrapure water beyond that which is achieved from other desalination processes.

4.2.3 Nanofiltration (NF)

Nanofiltration is similar to reverse osmosis in that it is a pressure driven membrane process, but the pores in the membranes are larger than those in reverse osmosis systems. This allows more particulates to pass through during the NF desalination process. Nanofiltration is more suitable for groundwater or possible brackish water desalination and is not a good fit for seawater desalination. The process is very efficient at removing nitrates from the water. Future advances in the nanofiltration process such as multiple pass systems might give rise to future consideration for seawater desalination uses. Nanofiltration has a TRL of 9, but is not currently suitable for use with seawater.

5 PROCESSES SUITABLE FOR COMMERCIAL USE WITH OTEC

- RO, MED-VC, MSF-VC selected for evaluation of use with OTEC
- All three meet all initial requirements set forth
- Most other processes not commercially viable at 50 MGD

Upon initial screening of the many desalination technologies mentioned in section 4 there are three that stand out as being suitable for commercial use as part of an OTEC system at the capacities considered in this study. Multistage flash desalination and multiple effect distillation are suitable to be joined with an OTEC system when the processes are altered slightly to use a vent compressor instead of a thermal resource for the creation of water vapor. Reverse osmosis works as a stand alone desalination system that is powered by the electricity generated from the OTEC facility.

These processes were selected for evaluation via a multi-criteria decision analysis based on the fact that they meet all of the necessary criteria for commercial water production set forth for this study. These criteria are:

- Capable of producing up to 50 MGD
- Commercially proven and reliable
- Capable of producing potable water within WHO and USEPA standards
- Minimum disruption of energy production (require the least amount of electricity on a per unit production basis and consume the least amount of water / thermal resources prior to OTEC electricity production)
- Produce potable water in a cost-effective manner
- Compliant with all applicable environmental regulations
- Meet any applicable building codes or ABS requirements
- Minimize plant footprint on the platform as much as possible
- Maintenance requirements practical for a commercial operation on an offshore floating platform

MSF, MED and RO are all well established seawater desalination techniques that meet all of the above criteria. Reverse osmosis has two separate possibilities, as warm or cold water can be used. Both offer certain advantages over the other and will be evaluated for use with an OTEC system. Most of the other technologies discussed in section 4 are eliminated because they are not commercially proven or not practical solutions for a capacity of 50 MGD. Some, such as solar distillation, require such large space requirements they would not be technically feasible for use on an offshore platform.

6 ENVIRONMENTAL CONSIDERATIONS

- Both SWRO processes determined to be more environmentally favorable than MED-VC and MSF-VC
- Environmental issues for all processes mostly stem from discharge

There are two principal categories into which the environmental impacts of a desalination plant can be split: those created during the construction of the plant itself, and those created during operation. The four seawater desalination technologies selected for further investigation for potential integration into an OTEC facility; multi-stage flash with vent compression (MSF-VC), multi-effect distillation with vent compression (MED-VC), warm seawater reverse osmosis (SWRO) and cold seawater reverse osmosis (Cold-SWRO), have different measurable effects on their surrounding environments. Through careful design and planning during construction and operation of either of these desalination configurations in conjunction with an offshore OTEC facility, many of the main environmental issues associated with desalination plants can be significantly mitigated or eliminated altogether. Construction impacts and intake pipe issues will be quite similar for all four processes. The main differences will occur from the brine discharge and the carbon emissions. The four technologies are evaluated over twelve categories involving the brine discharge and the carbon emissions. Each is given a score on a scale of 1 – 4. The scores are totaled and the lowest score signifies the most favorable from an environmental aspect.

6.1 Construction

Construction and installation of the intake and outfall pipes, as well as the desalination plant itself, can disturb the surrounding ecosystems. Traditionally, almost all desalination plants, with the exceptions of those on maritime vessels and oil platforms, are land based. Therefore, the plant and pipes have obvious impacts on the developed land and nearshore coastal region. Construction of the plant typically requires movement and leveling of sediment. This perturbation can lead to disturbing certain sensitive species on land and in the nearshore region by modifying natural sediment paths temporarily increasing turbidity and altering nutrient levels in the nearshore environment. Even though the pipes are typically buried via trenching or tunneling under the sediment as a means to limit the impact on the environment and exposure to external forces, there is still sediment and biota disruption as this methodology is only so effective. Additionally, exposed pipelines can also interfere with local water currents and act as an artificial breakwater [55].

The construction process for land-based desalination plants can also cause resettling of sediments, nutrients and pollutants. This resettling can cause the burying of benthic organisms, or possibly destroying habitats along the pipeline corridor, which could take years to recover [55]. Similarly, the possible dredging and drilling for pipeline installation would cause noise emission that could disturb organisms sensitive to sound vibrations. If the pipe itself is lying on the ocean bottom or elevated above the bottom, certain organisms could make their home under the pipe creating a reef type community [54]. The entire facility could also cause visual and acoustic disturbances both on land and in the water. Just as in any construction, there would be various atmospheric emissions that also could negatively impact the environment, partly in the form of greenhouse gases [38].

Building a desalination and OTEC facility offshore on a floating platform eliminates many of the environmental issues surrounding the construction phase. No land will be affected, and there would be minimal oceanic disturbances as the plant will likely be assembled in a suitable shipyard designed

to accommodate such construction disturbances. The additional environmental disruption introduced by the integration of a desalination process into an OTEC platform during construction would be essentially negligible except for the added carbon footprint introduced by additional materials required by the desalination facility.

6.2 Intake Pipe Issues

There are two principal environmental issues associated with water intake pipes when considering desalination facilities; entrainment and impingement. Entrainment occurs when organisms such as eggs and larvae are drawn into the plant with the intake waters at the pipe entrance. This becomes a larger issue when there are multiple pipes in the area or the pipe intake is located near a species that is valuable to the ecosystem, commercially viable, or is on the endangered species list [54]. The second issue for water intakes, impingement, occurs when an organism that cannot fit through the pipe inlet screen gets impinged, or stuck, against the entrance of the intake pipe. Similarly, impingement also becomes even more concerning when the species involved are endangered or protected such as sea turtles and sea snakes, or if the affected species is commercially viable [54]. Regardless of which type of desalination plant is built, all require intake pipes to serve as a conduit for the resource water to be desalinated, and thus all have these associated impacts.

Impingement and entrainment issues are directly related to the flow rate and flow velocity of the desalination plant intake. This effect is created due to the fact that the more water you take in and the higher the through-screen velocity, the more organisms will be entrained or impinged within the intake infrastructure. Because the SWRO plants have much lower flow rates and resource requirements (higher recovery rates) than MSF-VC and MED-VC, they experience less of an issue with impingement and entrainment and can be designed with lower flow velocities to meet the same production capacity requirements. Cold-SWRO is anticipated to have significantly less impingement or entrainment than SWRO due to the significantly lower bio-activity found at OTEC deep water ocean depths (i.e., >800 meters). Additionally, since MED-VC plants, when compared to MSF-VC plants, have a lower rate of recovery, MED-VC will require a slightly higher flow rate than MSF-VC and are anticipated to experience the most impingement and entrainment of the four technologies selected for additional investigation [84][64].

Integration of the desalination plant with an OTEC platform in an open-ocean location with depths in excess of 800 meters moves the plant away from more fragile ecosystems and significantly reduces or eliminates some of these intake concerns typically associated with land-based facilities. Prior environmental study and proper site selection to avoid endangered, protected, or commercially viable species will greatly reduce entrainment and impingement issues associated with the desalination system intakes. Similarly, by integrating the surface water intake pipes of the OTEC and desalination facilities into one intake pipe, the problems corresponding to impingement and entrainment can be reduced. Even further reduction in impingement and entrainment issues can be accomplished in regards to the desalination facility if the water utilized in the OTEC system is subsequently utilized as the resource water for the desalination system.

Impingement issues can be further mitigated by reducing the through-screen velocity at the source intake to meet current EPA regulations for power plant and cooling water intakes. EPA CWA Section 316(b) limits all cooling water intake through-screen velocities to less than 0.5 feet/sec at pipe intake. This can be accomplished by adding a suitable intake structure to increase the surface area of intake and thereby reduce intake velocity exposure to local organisms effectively reducing or eliminating impingement at source intake.

Because there are so few organisms living at depths of 800+ meters, cold-SWRO ranks number one in terms of dealing with impingement and entrainment. The next three technologies all have warm water intake pipes and are thus ranked by their flow rates because impingement and entrainment rates are directly correlated with the amount of water entering the intake pipe. Thus, warm-SWRO ranks number two, followed by MSF-VC, and MED-VC.

6.3 Discharge Issues

The principal environmental impact differences between the competing commercial desalination technologies being investigated for integration with an OTEC system are encountered in the discharge water following desalination and water treatment procedures during plant operations. These differences are due to the varying processes occurring in each type of plant, the chemical treatments required and the by-products produced during each desalination process.

6.3.1 Salinity

The salinity of the brine discharge into the ocean varies with each type of desalination configuration due to different recovery rates for each technology. In comparison to MSF-VC and MED-VC plants, RO plants have an order of magnitude higher recovery rate which results in a higher salinity in the concentrated brine reject stream. Both SWRO and Cold-SWRO plants can be designed with an estimated recovery rate of approximately 40%. This recovery rate corresponds to an associated increase in salinity of approximately 64% for the brine discharge. In the RO process, temperature has an inverse affect on product flow through the membrane; a high temperature increases product flow, a low temperature decreases product flow. All Reverse Osmosis membranes and systems are rated at 25ºC (77ºF). To find the membrane permeate rate at another temperature (i.e., Cold-SWRO), a temperature correction factor (TCF) is used to determine the permeate flow at the resource water temperature. See Table 6-1for TCF at various temperatures.

Table 6-1 Reverse Osmosis Temperature Correction Factors (TCF)

Temperature Correction Factors (TCF)					
ºC	TCF	ºC	TCF	ºC	TCF
1	3.64	13	1.61	25	1.00
2	3.23	14	1.54	26	0.97
3	3.03	15	1.47	27	0.94
4	2.78	16	1.39	28	0.91
5	2.58	17	1.34	29	0.88
6	2.38	18	1.29	30	0.85
7	2.22	19	1.24	31	0.83
8	2.11	20	1.19	32	0.80
9	2.00	21	1.15	33	0.77
10	1.89	22	1.11	34	0.75
11	1.78	23	1.08	35	0.73
12	1.68	24	1.04	36	0.71

In this investigation the reported recovery rates for the two different SWRO plants are the same because the design of the cold-SWRO plant can be modified to produce the same permeate capacity

and recovery rate. The modified design resulting in a higher recovery rate does require more energy and more membranes. Without design modifications, the cold-SWRO recovery rate would be much less than that of the warm-SWRO plant by a factor of about 2.

Table 6-2 Salinity Profile Near Oahu

Salinity Profile	
Depth (m)	**Salinity (ppt)**
10	36.518
50	36.541
100	36.599
200	36.714
300	36.505
400	36.273
500	35.947
600	35.580
700	35.347
800	35.171
900	35.075
1000	35.036

Even though the recovery rates and percentage change in salinities of the resource and brine discharge streams are similar for both types of RO plants, the Cold-SWRO discharge is anticipated to have a slightly lower salinity than that of the warm water SWRO. This is due to the fact that the deep cold water starts off with a lower salinity than the warm surface water as shown in Table 6-2.

In MSF-VC desalination plants integrated into an OTEC system, the recovery rate is estimated at 2.9-3.4%, which only increases the salinity of the brine reject water by about 3-3.5% [84][64]. Similarly, MED-VC plants that are integrated into an OTEC facility possess slightly lower expected recovery rates of about 2.4-3.4%, thereby increasing the salinity of the discharge water by approximately 2.5-3.5% [64].

Organisms and ecosystems have certain thresholds for the level of salinity exposure they can survive. High concentrations can be lethal to some marine life while others can adapt to minor changes and short-term exposures. However, high salinity in the brine discharge water at the point of release can cause mobile animals to evacuate the discharge area and stationary bio-organisms to perish causing major disruptions to local ecosystems if care is not taken to properly disperse the reject stream [54]. In land-based options, offshore diffusers can be used successfully to encourage plume dispersion at greater rates as well as locating the discharge point in areas of high current activity [55]. For platform OTEC options in open-ocean locations, discharge at a convenient depth and in areas of high current activity will encourage plume dispersion and diffusion effectively mitigating environmental impacts caused by brine discharge and elevated salinities.

Additional measures can also be employed for desalination plants integrated into OTEC systems to further reduce the effects caused by elevated salinity on the local ecosystem. The brine reject water can be mixed with the OTEC effluent streams to further dilute the brine prior to reintroduction into the open ocean. This is a very effective and environmentally sound strategy for reducing or eliminating the impacts typically associated with brine discharge into the ocean from desalination facilities.

In technology rankings, MED-VC ranks number one in terms of its discharge salinity because it has the lowest recovery rate, which means the change in salinity will be the smallest in the discharge. MSF-VC is a very close second with only slightly higher salinity increase. In ranking cold and warm-SWRO plants, although they are built to have the same recovery rates and thus salinity increases, cold-SWRO comes out ahead because of a lower initial salinity content in deep seawater, causing less of a change in ambient seawater salinity than warm-SWRO plants.

6.3.2 Temperature

For desalination (and power facilities), the World Bank and other regulatory environmental agencies have set a limit for thermal discharges at 3˚C above the ambient waters at the point of discharge [54]. Similarly, it is also important that discharge flows not go too far below ambient water temperatures either, as a cold shock to localized biota can cause organisms in the area to suffer [71]. Thermal effects of the desalination plant discharge can have significant impacts on the local area if excessive in either direction. The ambient level of the water could already be close to the physiological limit of endemic species, and thus an increase or decrease in temperature could be harmful [37]. Organisms that are non-migratory, including larvae will be most affected by the cold water and could possibly even be killed by large temperature differentials [71].

When integrated with an OTEC system, there is no “free” heat source for MSF or MED to utilize thermal desalination so both technologies rely on mechanical vent compression to produce the necessary phase change. Therefore, both technologies work at lower temperatures and lower pressures to desalinize the water and thus discharge water that is generally cooler than ambient water temperatures at the point of discharge.

Assuming a mixed discharge of warm and cold resource streams (at OTEC inlet temperatures) with the brine concentrate in an MSF-VC desalination process, the mixed discharge is anticipated to be approximately 15.5˚C +/- 0.5˚C [84]. Similarly, the temperatures of the mixed discharge in the OTEC integrated MED-VC plant is estimated at 18-19.2˚C +/- 0.5˚C [64]. These discharge temperatures fall into ranges of approximately 5-15˚C below surface water temperatures of 25-30˚C, with MED-VC discharge water slightly closer to anticipated ambient temperatures at typical OTEC design discharge depths (50 – 80 meters).

Since SWRO plants utilize pressure to force the water through the membranes, there is little to no temperature difference experienced between the water at its intake and discharge [54]. The implication for cold-SWRO plants, however, is that the discharge waters will have a similar temperature to the intake water, which is approximately 18-20˚C below the ambient temperature of the water at the point of discharge. Therefore, the discharge of the cold-SWRO plant is anticipated to have the largest thermal effect on the surrounding environment of the discharge pipe related to discharge temperature. For warm-SWRO, there are no thermal impacts associated with the discharge of the reject brine from the desalination facility.

Warm-SWRO ranks number one in minimizing the effects of discharge temperature because there is negligible difference between the temperature of the brine and that of ambient seawater. Because MED-VC and MSF-VC discharge a combination of warm and cold seawater, they follow in the technology rankings of number two and three, with MSF-VC slightly more attractive because the discharge temperature is closer to ambient temperature. Coming in last is cold-SWRO because the discharge temperature is not much different from the resource water which comes from depths of 800+ meters, which has temperatures of approximately 18-20°C below ambient water temperature.

6.3.3 Plume Density

The discharges of each desalination technology will have different densities directly related to their discharge temperature and salinity. Discharges with lower densities and similar discharge velocities will tend to migrate slower away from the discharge point and remain closer to the discharge outlet than effluent discharges with greater densities. The potential for lower density discharges to “hover”

around the discharge point will negatively affect the diffusion effectiveness of the plume and could adversely impact open water organisms more than higher density discharges [55]. Conversely, larger differences in density between the discharge water and the water in the surrounding environment will cause the discharge to follow longer plume diffusion trajectories effectively creating more opportunity for dilution. This, in turn, results in less of an impact on organisms in the area of effluent discharge [71].

The ambient temperature, high salinity content brine reject water produced from an SWRO plant's discharge has an increased density which will create a negatively buoyant plume at discharge. Similarly, cold-SWRO plants have a discharge with temperatures approximately 15 to 20 ˚C below ambient water temperatures and a salinity level similar to a SWRO plant discharge. Therefore, the discharge water of a cold-SWRO plant is also negatively buoyant. Although the warm-SWRO discharge water has a slightly higher salinity due to a slightly higher source salinity, the temperature difference of the cold-SWRO is significantly higher and should prove to create a more negatively buoyant plume than that of the warm-SWRO.

MSF-VC and MED-VC technologies are estimated to have much lower salinities than both SWRO technologies due to lower recovery rates and thus have discharges that are much less dense when compared to those of SWRO plants. When comparing MSF-VC with MED-VC plants, MSF-VC discharges are reported to have slightly lower temperatures and slightly higher salinities than the discharge of MED-VC plants [84][64]. This difference results in an anticipated higher plume density for MSF-VC plants.

The highest ranking technology is that with the highest plume density, since it will lead to a quicker dispersion of the discharge in the open ocean. The number one technology is thus cold-SWRO, which has the highest density due to its much colder discharge water compared to the other technologies with only a slightly less salinity content than warm-SWRO. Ranked second is warm-SWRO because of the high salinity content of the discharge. Based on a 40% recovery rate, the brine discharge salinity is about 64% greater than that of the ambient seawater into which it is discharged. MSF-VC followed by MED-VC round out the rankings with minor increases in salinity and decreases in temperature, with MSF-VC slightly ahead due to a lower temperature and higher salinity content discharge than MED-VC.

6.3.4 Dissolved Oxygen

Dissolved oxygen levels in the respective discharges also vary by desalination technology. In warm-SWRO, surface water is utilized as the resource water for desalination purpose and pressurized through a permeable membrane to obtain the product water. Therefore, the DO concentration of the brine reject and discharge water will be the same as ambient seawater from which it is derived [54]. In the cold-SWRO process integrated with an OTEC system, the resource water for desalination is obtained from depths in excess of 800 meters. The discharge will have lower DO content than surface water due to the significantly lower oxygen content in the source water drawn from those depths [74]. In MSF-VC and MED-VC technologies, DO levels are expected to be below ambient seawater levels in the discharge waters due to significant levels of oxygen deaeration expected during the desalination process under vacuum conditions and the use of oxygen scavengers in the cleaning process [74][55]. The level of DO anticipated in the MSF-VC and MED-VC discharge should be much lower than that of the cold-SWRO discharge because nearly all of the available dissolved oxygen should be deaerated from the water at the vacuum conditions required to perform the phase separation at ambient surface seawater temperatures [74].

A large plume of oxygen deficient water created by the desalination plant discharge could prove harmful to organisms that swim through or get entrained in the discharge plume. However, if integrated with an OTEC power plant and mixed with OTEC waters, the DO discharge impact should be greatly mitigated or eliminated due to the available volume and dilution experienced within the mixed discharge. Figure 6-1 shows a typical dissolved oxygen profile for the tropical Pacific Ocean [12].

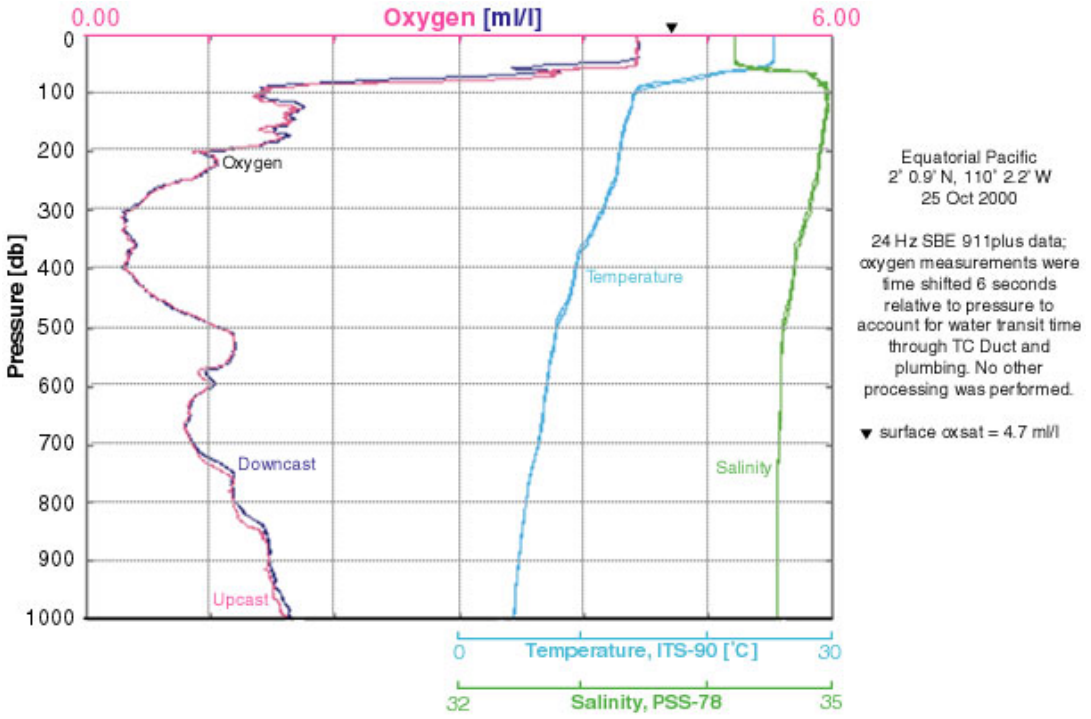


Figure 6-1 Dissolved Oxygen Profile [12]

Once again, rankings in this category are determined by which technology minimizes the difference between discharge DO and ambient DO levels. The warm-SWRO technology ranks first, as it does not change the DO content of the resource surface water and is therefore expected to produce a discharge with ambient DO content. Second is cold-SWRO; although it starts off with less DO than surface water, there is no significant expected removal of the dissolved oxygen through the process operation as there is in MSF-VC and MED-VC. The two latter technologies both remove nearly all the DO in the resource water during the vent compression and vacuum draw down.

6.3.5 Biofouling Control Additives (Chlorine)

Along with other chemicals inserted into the incoming stream of seawater, as part of the pre-treatment for each desalination option, chlorine is typically added in small doses in order to prevent biofouling. Biofouling is a process in which polymeric matter adsorbs to a solid surface, which then allows film-forming pioneer-bacteria to settle, followed by secondary periphytes, microalgae, protozoa, fungi colonies and then debris: all which can significantly interfere with heat transfer and increase flow friction lowering the effectiveness and efficiency of the desalination process [36]. Chlorine is typically inserted into the resource stream at dosages of approximately 0.4 - 4.0 mg/l in order to deter the initial

bacterial film formation required for larger organisms to adhere to the system surfaces. It is also necessary to insert periodic short-term increases in chlorine dosages to kill any remaining bacteria beginning to build up resistance to the chlorine [54].

Chlorine itself is very toxic to a wide spectrum of marine species which have varying levels of chlorine resistance depending upon their species sensitivity and life cycle stage. The EPA recommends that marine environments should not be exposed to chlorine levels of more than 13 µg/L in the short term and 7.5 µg/L in the long term [54].

Since cold-SWRO plants would use OTEC resource waters from depths in excess of 800 meters, it is anticipated that there is no need to use chlorine in the system due to the lack of viable bacteria and organisms at that depth. If any chlorine were to become necessary, it would be very minor with negligible impact on the local environment. Therefore, chlorine at the discharge site of a cold-SWRO facility should prove a non-issue.

In typical warm-SWRO plants, the chlorine utilized to deter biofouling in the resource stream must be neutralized through the use of sodium bisulfite before it makes contact with the RO membranes to prevent damage. This action causes chlorine concentrations at the discharge point of SWRO plants to be very low or non-detectable. Conversely, in MSF and MED plants, the chlorine used is often discharged along with the waste stream in varying concentrations, and if not neutralized can be harmful to marine life in the mixing zones [54].

To mitigate the amount of chlorine dispersed into the water with the system discharge stream, the desalination plant can take several mitigating steps. One would be to treat the water before it is discharged with sodium bisulfite to neutralize the chlorine as is normal practice in SWRO systems. Another option is to replace the chlorine with a different chemical, such as chlorine dioxide, which is a similar strong oxidant. The chemical is much less toxic with no observed effect at concentrations one thousand times greater than chlorine when exposed in open seawater [54]. Chlorine dioxide has not currently gained huge commercial acceptance, but is being used in an RO plant in Tampa Bay, Florida and certain areas of the Gulf [54]. Locating the desalination plant's discharge pipe away from important ecosystems, or placing it on an OTEC platform far from the coast and mixing it with the discharge streams of the OTEC plant would further alleviate the impacts associated with system chlorination.

6.3.6 Biofouling Control Byproducts- Trihalomethanes (THMs)

Chlorination of seawater can also initiate the formation of trihalomethanes (THMs), which are known carcinogens in humans and can also prove detrimental to the local ocean environment. The THMs are formed when the chlorine reacts with organic compounds naturally present in the seawater. This process can become accelerated if the organic carbon in the water is enhanced by the pollution of hydrocarbons [36]. The main product of these reactions is bromoform, which accounts for about 95% of the total THMs injected into the coastal waters from the chlorination process. These chemicals can stress marine organisms at low concentrations and potentially be harmful with a chronic input of high concentrations [88]. Again, since these form when the organic compounds such as those found in seawater react with chlorine, the THMs are a more significant concern in MSF-VC and MED-VC plants should they be used in OTEC water production scenarios.

The EPA recommends a standard limit of 100 µg/L for total THMs allowed in coastal or ocean waters. Detected levels of THMs outside of existing commercially operational desalination plants have been

measured at less than 0.5 µg/L, demonstrating that the threat due to THMs is minimal [88]. Due to this fact, no further mitigation steps need to be implemented; however, full ecological effects of continuing dosages of THMs over a long period of time have not been researched fully and should be further studied [88]. Locating the discharge pipes in waters away from sensitive or critical ecosystems would further minimize the small risk that THMs impose, and could be further mitigated by integrating the desalination system on an OTEC platform offshore.

Biofouling control rankings are dependent on the amount of chlorine that is used in the desalination plant facility. Since the chemical itself as well as its byproducts have effects, the cold-SWRO would be the preferred technology because it is anticipated not to require source-stream chlorination due to the lack of bacteria in the deep source water. The second preferred desalination strategy would be warm-SWRO, which neutralize the chlorine before it is discharged into the ocean and thus reduces its impact on the environment. Least attractive would be the MED and MSF technologies which both are typically designed to release chlorine with the rest of their discharge.

6.3.7 Removal of Suspended Matter (SWRO plants only)

In warm-SWRO plants suspended matter inherent in the resource waters needs to be removed prior to the water/membrane interface to prevent membrane "clogging." This operation is typically performed as a pre-treatment stage. Typically, the matter is removed by a pre-filtration system by dosing the resource water with coagulants and polyelectrolytes inserted in amounts correlated to the amount of suspended material in the intake water flow. The amount of coagulants and polyelectrolytes can range between 1 to 30 mg/L and 0.2 - 4 mg/L, respectively [54]. The collected residual matter can then be discharged back into the ocean or as sludge onto land. Although the chemicals are non-toxic to aquatic life, other negative effects from the discharge of the matter could result. The backwash causes a plume of red brines that can decrease light penetration affecting the productivity of macroalgae, seagrasses, or corals if present in the area of discharge [55]. Pre-filtration is limited in cold-SWRO plants due to the lack of suspended matter typically present at 800+ meters below sea level. MED-VC and MSF-VC do not need to filter out suspended matter because those processes do not have sensitive membranes. Also, suspended solids do not interfere with heat transfer and pass through the process with the reject streams.

Again, the impacts of suspended solids removal can be minimized by locating and operating the facility in a remote area away from the sensitive coastal regions which typically have higher bio-activity and suspended solids in resource waters.

Because MED, MSF and cold-SWRO do not need to remove suspended matter from their systems due to a lack of sensitive membranes or matter, the environmental concern associated with coagulants turns out to be a non-issue. Only warm-SWRO ranks behind these three because of the use of coagulants to remove the suspended matter from the system.

6.3.8 Scaling Control

In desalination plants it is important for maintaining efficiency and corrosion purposes to reduce the scaling that occurs within the plant. The main culprit present in the seawater causing scaling is the calcium carbonate which can be controlled by the addition of sulphuric, or hydrochloric acid [54]. These acids, along with BELGARD EV2000, the most common antiscalant in commercial plants, prevent dissolved materials from precipitating, settling, and baking on surfaces [36]. All types of desalination plants require antiscalants and thus the environmental implications need to be examined.

Due to higher flow rates and resource water requirements in MED-VC and MSF-VC, more antiscalants will be required and subsequently discharged into the ocean by these types of facilities than would be expected by either type of SWRO plants.

The acids themselves upon interaction with seawater are neutralized by the time the discharge stream reaches the open ocean because seawater acts as an excellent buffer [55]. The toxicity of antiscalants, including BELGARD EV2000, has been determined to be ecologically safe [55][36]. There are some concerns, however, about antiscalants and their residence times in the water column. This concern, as well as the possibility of interference with biologically essential trace metal ions needs to be researched more thoroughly [37].

Although the effects of antiscalants are considered minimal on the environment at levels experienced in desalination processes, locating the plant far from sensitive ecosystems is a precautionary measure that should be taken whenever possible. Again, further mitigation of the potential impacts of antiscalants can be achieved through integration of the desalination process with an OTEC facility and mixing/diluting the discharge with the OTEC effluent waters under open ocean conditions.

The amount of scalant inhibitors that are inserted into the water is correlated with the flow rate of the seawater through-put, which causes the technologies with the lowest flow rates to rank the highest. Both cold and warm-SWRO have lower flow rates than the other two technologies due to higher recovery rates, making them the preferred technologies. Because the flow rate of MED-VC is slightly higher than MSF-VC, MSF-VC is preferred over MED-VC.

6.3.9 Antifoaming agents (MSF & MED only)

The foaming of seawater takes place in the distiller section of the MSF-VC and MED-VC plants. The process of foaming is caused by a surface phenomenon which occurs due to the quantities of organic compounds and surfactants that exist in seawater [42]. The foam itself affects the heat transfer by effectively reducing the efficiency of the phase change process. Often, to reduce foaming, MSF and MED plants will use polyethylene and polypropylene glycol as foaming deterrents; simple detergents that are not toxic to the environment. The main issue associated with antifoaming agents is not the toxicity, but rather the fact that it remains in the environment for a long period of time due to poor biodegradability [55]. The SWRO technologies do not require antifoaming agents because the resource water is not required to change phases (i.e., liquid – vapor) to produce potable water.

Attempting to achieve an 80-90% degradability of the detergent can mitigate the effects of the discharge water on the environment [36]. Further mitigation of the potential impacts of antifoaming agents can be achieved through integration of the desalination process with an OTEC facility and mixing/diluting the discharge with the OTEC effluent waters under open ocean conditions.

Because antifoaming agents are only required in MSF-VC and MED-VC technologies, the environmental concern of these foam inhibitors is eliminated in both types of SWRO plants, leading to a number one rank for each. MSF-VC and MED-VC both require the use of detergents to eliminate foam in the system and thus rank behind the SWRO technologies. There is no discernable means of distinguishing between the impacts of these technologies, but each which would have a greater environmental impact than SWRO due to anti-foaming agents.

6.3.10 Corrosion

Another concern associated with desalination plants is the potential for corrosion of system piping and components that could discharge heavy metals ions into the ocean. MSF and MED plant components are typically built using copper-nickel alloys, which naturally corrode into reject streams at about 15-100 µg/L [55]. The natural background rate of copper in the ocean itself can range from 0.1 - 100 µg/L, which can make it hard to distinguish what the anthropogenic effect is upon the measured amount. The EPA thus has recommended a maximum copper output of 3.1 µg/L long term and 4.8 µg/L short term for desalination discharge streams [55]. Although copper is an essential micronutrient, it can be quite toxic in excess amounts. When discharged from the desalination facility, the copper ions will absorb into suspended matter and sink down, accumulating in the sediments [36]. By accumulating in the sediments, copper can have an adverse effect on local biology, and once it assimilates into benthic organisms, the basis of the food chain, it will be passed on to other organisms and lead to bioaccumulation and biomagnification within the food chain [104][55].

In comparison, RO plants typically use stainless steel piping and system components which have a much greater resistance to corrosion than the copper-nickel alloys used in MSF or MED systems. SWRO plants use non-metals and stainless steel to avoid contaminating the filtered feed going through the membranes, resulting in contamination an order of magnitude less than MSF plants [73]. Although using stainless steel results in the possibility of introducing other metals, such as chromium, nickel and molybdenum, the general corrosion of the stainless steel is essentially zero and will not have a measured effect. Typically for SWRO plants, the correct choices of stainless steel grade are 6% molybdenum grades such as UNS No S31254 and NO8926 [73]. However, if the wrong grade of stainless steel is used, harmful corrosion can occur introducing unnecessary heavy metals into the discharge streams.

The principal concern over heavy metal ions from desalination plants is caused by their cumulative properties and effect on the environment (load is what matters [36]); dilution of the discharge stream does not reduce the impact. It is thus important to utilize stainless steel components whenever possible to reduce corrosion issues.

Like other environmental concerns associated with desalination plants, the magnitude of the effects of corrosion contaminants depends primarily on flow rates. Not only do SWRO plants have lower flow rates, but they also use a stainless steel that minimizes corrosion. The copper-nickel alloys that MSF-VC and MED-VC plants use are much more susceptible to corrosion and thus receive a lower rank than SWRO plants. MED-VC receives a slightly lower ranking than MSF-VC due to the larger flow rate, which should increase the load of the heavy ions in the water column.

6.3.11 Cleaning Chemicals

For SWRO plants (both warm and cold), dependent upon what is being cleaned, either an alkaline solution with a pH of about 11 - 12 is used in order to remove silt deposits and biofilms from membranes, or an acidic solution with a pH of about 2 - 3 is used to dissolve metal oxides or scales [54]. Additionally, detergents, oxidants, and biocides are applied in order to further aid in cleaning and disinfecting the membrane as required [55]. Oxidizing or non-oxidizing biocides used in SWRO plants can be hazardous to marine life when released into the surface water, and thus have a more harmful effect on the environment [54].

In MSF and MED plants, the cleaning process is much simpler, as the plants are typically washed with warm acidic seawater containing corrosion inhibitors periodically [55]. Often these cleaning solutions are discharged into the ocean with the rest of the waste stream, either gradually or all at once. In order to mitigate the effects of these cleaning processes, locating the desalination facility in conjunction with an OTEC plant offshore away from vital ecosystems would minimize the effects on marine life. Also, utilizing the same discharge pipe as the OTEC facility would result in the further dilution of the cleaning chemicals in the discharge to minimize environmental impact.

Although each type of desalination facility uses some combination of chemicals to clean their systems, there is more of a concern with SWRO plants because of their use of numerous chemicals necessary to clean the sensitive membranes. For this reason, the relatively less harmful cleaning processes of MED-VC and MSF-VC plants rank higher in minimizing environmental impact. Both types of SWRO technologies require the cleaning of the membranes and thus are expected to have similar impacts.

6.4 Energy Use/CO_2 Footprint

By integrating any of the competing desalination technologies with the offshore OTEC facility, there are no harmful greenhouse gas emissions associated with energy use. This is resultant of the fact that the closed-cycle OTEC technology can provide sustainable base load power with zero emissions for the desalination plant's operational energy requirements.

However, not all of the desalination technologies presented are void of carbon emissions themselves. Specifically, since the MSF and MED technologies are coupled with mechanical vent compression instead of the more conventional thermal heating to perform the liquid/vapor phase change, there will be significant deaeration of CO_2 from the resource waters. At the low pressures required to induce phase change at typical tropical ocean ambient surface seawater temperatures, the desorption of noncondensable gases such as CO_2 from MSF-VC and MED-VC plants can be expected to emit up to 1,130 tonnes CO_2/year for a 50 MGD water desalination plant and up to 22.6 tonnes CO_2/year for a 1 MGD water desalination plant [84]. A cold-SWRO plant can also potentially release CO_2 if a free surface is introduced in the process due to lower atmospheric pressures. However, this can be prevented through proper system design. Warm-SWRO technologies are able to avoid all of the above emissions.

The rankings of CO_2 emissions for the various technologies are not dependant upon their energy use, but rather the deaeration of the CO_2 in the system. Since warm-SWRO does not encourage any deaeration in its process, it ranks first with no operational carbon emissions. Cold-SWRO plants that have the potential to release carbon dioxide if a free surface is introduced in the process have the second least impact in regards to CO_2 emissions. Least attractive are MED-VC and MSF-VC technologies, which can be expected to emit large quantities of CO_2 through the process of deaeration of the resource water at system pressures.

6.5 Site Selection

A common theme among the mitigating solutions to the environmental impacts listed above has centered upon diluting the discharge and, even more importantly, proper site selection. In nearly all circumstances, locating the desalination facility in a remote coastal location away from sensitive ecosystems or areas of high bio-activity, or by placing the desalination facility on an OTEC platform in

the open ocean, there will be fewer environmental impacts associated with the desalination process. Construction and placement of the facility offshore will not disturb coastal ecosystems, fewer species will be entrained or impinged in intake pipes, and the problems with the discharges of the facility, such as the high salinity levels, thermal pollution, chlorine, THMs, coagulants and polyelectrolytes, antifoaming agents, and antiscaling chemicals will all be diluted quickly in the OTEC effluent streams and in the open water after the initial mixing zone. Essentially, if there is limited exposure to local endangered, protected, or commercially viable species near the selected site location as well as no sensitive ecosystem, the discharges from the desalination systems can be designed to have an extremely limited environmental impact on the affected region.

6.6 Environmental Impacts Summary

The rankings that were given at the end of each section are compiled in the following matrix (Table 6-3). From the matrix, it can be concluded that both SWRO technologies have lesser impacts on the environment than the MSF-VC, and MED-VC technologies. The environmental impact differences between the two SWRO technologies are essentially indiscernible in this analysis in spite of the fact that the cold-SWRO utilizes deep-water resource water with limited bio-activity.

Table 6-3 Environmental Concern Matrix

Environmental Concern	SWRO	Cold- SWRO	MED-MVC	MSF-MVC
Impingement/Entrainment	2	1	4	3
Discharge salinity	4	3	1	2
Discharge temperature	1	4	2	3
Discharge plume density	2	1	4	3
Discharge DO	1	2	3	3
Biofouling control	2	1	3	3
Coagulants	2	1	1	1
Scalant inhibitors	1	1	3	2
Foam inhibitors	1	1	2	2
Corrosion contaminants	1	1	3	2
Cleaning chemicals	2	2	1	1
CO_2 emissions	1	2	3	3
TOTALS	20	20	30	28

The difference in composition of the deep ocean resource water and the surface water into which it is discharged balances out the impacts of the additional pre-treatment required by SWRO in the multi-criteria decision analysis. The MSF-VC and MED-VC desalination technologies have significantly more impact on the environment than the SWRO options. This is due to the fact that the flow rates required to achieve the same production level of fresh water are much higher than those of SWRO plants, and therefore have a greater impact on the oceanic environment. Table 6-4 below is a summary of the effects of the environmental impacts of the different desalination technologies that were examined in this study.

Table 6-4 Environmental Impacts of OTEC Desalination Technologies

	SWRO	Cold- SWRO	MED-MVC	MSF-MVC
Intake Pipe Issues				
Impingement/Entrainment	Entrainment and Impingement an issue, but minimized because of lower flow rate	Almost none because of lack of organims at 1,000 meters depth	Highest rate of impingement and entrainment due to high flow rates	High rate of impingement and entrainment due to high flow rates
Physical Properties				
Salinity	Up to 65,000 - 85,000 mg/L	Up to 65,000 - 85,000 mg/L; slightly less than warm-SWRO because of lower source water salt content at depth	About 50,000 mg/L	About 50,000 mg/L
Temperature	Ambient seawater temperature	- 15 to 20 ˚C below ambient seawater temperature	- 5 to 10 ˚C below ambient seawater temperature	- 5 to 10 ˚C below ambient seawater temperature; slightly more than MED
Plume density	Negatively buoyant	Negatively buoyant; more than warm-SWRO	Slightly negatively buoyant	Slightly negatively buoyant, more than MED
Dissolved Oxygen (DO)	Approximately same as ambient seawater	Below ambient seawater DO because of the low DO content of the source water	Below ambient seawater due to physical dearation and use of oxygen scavengers	Below ambient seawater due to physical dearation and use of oxygen scavengers
Biofouling control additives and by-products				
Chlorine	If chlorine or other oxidants are used to control biofouling, these are typically neutralized before water enters the membranes to prevent membrane damage	Should be no need for chlorine or other oxidant for biofouling in cold water. Very minor if at all necessary	Approximately 10 - 25% of source water feed dosage, if not neutralized	Approximately 10 - 25% of source water feed dosage, if not neutralized
Halogenated organics	Typically low content; below harmful levels	Virtually none because of lack of chlorine	Varying composition and concentrations, typically trihalomethanes	Varying composition and concentrations, typically trihalomethanes
Removal of suspended solids				
Coagulants (e.g. iron-III-chloride)	May be present if source water is conditioned and the filter backwash water is not treated	Not present (treatment not required)	Not present (treatment not required)	Not present (treatment not required)
Coagulant aids (e.g. polyacrylamide)	May be present if source water is conditioned and the filter backwash water is not treated	Not present (treatment not required)	Not present (treatment not required)	Not present (treatment not required)

	SWRO	Cold- SWRO	MED-MVC	MSF-MVC
Scale control additives				
Antiscalants	Typically low content; below harmful levels.	Typically low content; below harmful levels.	Typically low content; below harmful levels. More than SWRO because of flow rates.	Typically low content; below harmful levels. More than SWRO because of flow rates.
Acid (H_2SO_4)	Not present (reacts with seawater to cause harmless compounds, i.e. water and sulfates; the acidity is consumed by the naturally alkaline seawater, so that the discharge pH is typically similar or slightly lower than that of ambient seawater).	Not present (reacts with seawater to cause harmless compounds, i.e. water and sulfates; the acidity is consumed by the naturally alkaline seawater, so that the discharge pH is typically similar or slightly lower than that of ambient seawater).	Not present (reacts with seawater to cause harmless compounds, i.e. water and sulfates; the acidity is consumed by the naturally alkaline seawater, so that the discharge pH is typically similar or slightly lower than that of ambient seawater).	Not present (reacts with seawater to cause harmless compounds, i.e. water and sulfates; the acidity is consumed by the naturally alkaline seawater, so that the discharge pH is typically similar or slightly lower than that of ambient seawater).
Foam control additives (e.g. polyglycol)	Not present (treatment not required)	Not present (treatment not required)	Typically low content; below harmful levels.	Typically low content; below harmful levels.
Contaminants due to corrosion				
Heavy metals	May contain elevated levels of iron, chromium, nickel, molybdenum if low-quality stainless steal is used. Order of magnitude less than MSF/MED.	May contain elevated levels of iron, chromium, nickel, molybdenum if low-quality stainless steal is used. Order of magnitude less than MSF/MED.	May contain elevated copper and nickel concentrations if inappropriate materials are used for heat exchangers.	May contain elevated copper and nickel concentrations if inappropriate materials are used for heat exchangers.
Cleaning chemicals				
Cleaning chemicals	Alkaline (pH 11-12) or acidic (pH 2-3) solutions with additives such as : detergents (e.g. dodecylsulfate), complexing agents (e.g. EDTA), oxidants (e.g. sodium perborate), biocides (e.g. formaldehyde)	Alkaline (pH 11-12) or acidic (pH 2-3) solutions with additives such as : detergents (e.g. dodecylsulfate), complexing agents (e.g. EDTA), oxidants (e.g. sodium perborate), biocides (e.g. formaldehyde)	Acidic (pH 2) solution containing corrosion inhibitors such as benzotriazole derivatives	Acidic (pH 2) solution containing corrosion inhibitors such as benzotriazole derivatives
CO_2 emissions				
CO_2 emissions	No emissions	No emissions. However, if free surface is introduced in the process, potentially some CO_2 could be deaerated due to lower atmospheric pressures.	Up to 0.016 kg/m^3 fresh water produced. † This translates into approximately 22.6 tonnes CO_2/year for a 1 MGD plant and 1,129.9 tonnes CO_2/year for a 50 MGD plant.	Up to 0.016 kg/m^3 fresh water produced. † This translates into approximately 22.6 tonnes CO_2/year for a 1 MGD plant and 1,129.9 tonnes CO_2/year for a 50 MGD plant.

† - CO_2 outgassing rates taken from Oney, 1993. Flow rate estimates for water production levels taken from Rabas and Panchel, 1989.

7 EVALUATION

- Weighted summation method of multi-criteria decision analysis
- Cold seawater usage, electricity consumption and space requirements given heaviest weight
- Warm seawater reverse osmosis deemed best

There are several methods of seawater desalination and several factors to consider in determining which method is best suited for a particular situation. As mentioned in Section 5, there are three seawater desalination methods suitable for use with OTEC and more processes that can be used for further purification beyond desalting the seawater. These include:

- Thermal Processes: Multi-stage Flash Distillation and Multiple Effect Distillation
- Mechanical Processes: Reverse Osmosis, Electrodialysis and Vapor Compression
- Chemical Processes: Ion Exchange
- Hybrid Processes: Various combinations of the above processes

Of these processes, the three that are best suited for desalination of seawater in conjunction with an OTEC facility are multistage flash distillation with vent compression, multiple effect distillation with vent compression and reverse osmosis. Two forms of the reverse osmosis process are analyzed in this study. The utilization of warm surface seawater and cold deep seawater were evaluated as both have certain advantages. Electrodialysis and ion exchange can be used in conjunction with an OTEC facility, but these technologies are not for use in seawater desalination. They could be used to further purify water after it has passed through a MSF-VC, MED-VC or RO system for scientific or industrial water applications. However, for most drinking water applications and for the purpose of this study, MSF-VC, MED-VC and RO are assumed to provide pure enough product water that it does not need further purification.

Factors directly related to the various processes that must be considered include:

- Capital cost
- O&M cost
- Space and weight requirements
- Energy consumption
- Production capacity
- Product quality
- Environmental considerations

Each of these factors are evaluated with varying degrees of importance in an effort to determine the best desalination technology for use with an OTEC system as explained in the following sections.

7.1 Basic Evaluation Methodology

A multi-criteria decision analysis (MCDA) of the various possible means of seawater desalination in conjunction with an OTEC facility was performed to determine the best solution. The analysis employed the weighted summation methodology in order to establish the best water production system. The weighted summation method is described by Afify[1] in the following manner.

> …the utility of each alternative U_j is determined by the summation of weighted numerical values (scores) of each criterion (Eq. (1)). The alternative which has the greatest utility is the best alternative, Eq. (2).

$$U_j = \sum_{i=1}^{m} Wi * Sij \text{ for all j,} \quad (1)$$

$$U_{optimal} = U_j \text{ for all j} \quad (2)$$

Where, W_i is the weight of each criterion i, S_{ij} is the standardized score of criterion i and alternative j, m is the number of independent criteria, U_j is the utility of each alternative, and $U_{optimal}$ is the utility of the best alternative.

The criteria in this evaluation were all selected such that a low value is considered better than a high value. Thus, to standardize the scores Eq. (3) is used.

$$Sj = \frac{Max(sj) - sj}{Max(sj) - Min(sj)} \quad (3)$$

Where, sj is the score of alternative j, and Sj is the standardized score of the same alternative [1]. Not to be confused with the raw values of the criterion, a high standardized score is considered better than a low standardized score. This is illustrated in Table 7-2 at the end of this section. The standardized score is multiplied by the weight of the criterion to calculate the utility value of each alternative as shown in Eq. (1).

7.2 Evaluation Criteria

The criteria selected for the MCDA was chosen to take into account the factors that most greatly affect the overall cost of the product water and its compatibility with an OTEC facility, as well as the environmental impact associated with the particular desalination method. In all, four different desalination methods were analyzed across seven criteria. The four desalination methods analyzed were MED-VC, MSF-VC, warm SWRO (surface water) and cold SWRO (deep water). Each of these desalination processes were compared to one another based on capital cost, operations and maintenance cost, space requirements, environmental considerations, quality of product, amount of cold seawater required and electricity consumption. All of these criteria are quantitative in nature except the environmental category, which is mostly qualitative and is explained in section 6.

7.2.1 Specific Capital Cost

The specific capital cost is measured in units of $\$/m^3/day$. It has been shown by Afify and others that the specific capital cost is typically inversely proportional to plant size. This indicates that there could be a need for separate values in the specific capital cost category. Due to a lack of designs that consider MED-VC and MSF-VC as they would be constructed in conjunction with an OTEC system and the need for consistency across the alternatives, it is assumed in this study that the specific capital cost will vary similarly with plant capacity for each alternative. The capital cost was derived from Cipollina [15] and Mark M. Siah & Associates [64] for the MED-VC and MSF-VC facilities. For the reverse osmosis plants, the capital costs were derived from budget quotes from multiple RO system manufacturers obtained for previous projects. For the cold-SWRO system, the additional membranes needed and lack of pre-filtration requirements are taken into consideration. The capital cost is weighted at 10% of the total standardized score.

7.2.2 Operations and Maintenance Cost

Operations and maintenance costs are measured in thousands of US$ per year as given by Borsani [10]. These costs were originally calculated for plants of 205,000 m^3 / day production capacity and are the best estimates currently available for the 50 MGD (189,270 m^3 / day) capacity plant considered in this study. Also, for the purposes of this study, it is considered that while the O&M costs will be considerably lower for the 1 MGD plant than for the 50 MGD plant, the costs will decrease proportionally for each desalination technology when referring to the lower production capacity. The breakdown of the O&M costs is shown in Table 7-1. The cold-SWRO costs are based on the SWRO costs calculated by Borsani [10] when taking into account the increased number of membranes needed for the cold water system and the decreased need for pretreatment of the cold water due to a lack of biologics. The operations and maintenance cost is weighted at 10% of the total standardized score.

Table 7-1 Breakdown of Annual Operation and Maintenance Costs

Breakdown of O&M Cost					
Type of cost	**Units**	**MSF**	**MED**	**SWRO**	**Cold SWRO**
Chemical products for operation	KUS$	1500	1000	2500	2250
Chemical products for cleaning	KUS$	50	100	250	225
Operational labor	KUS$	400	600	500	500
Maintenance labor	KUS$	100	175	100	100
Membrane replacement	KUS$	0	0	2000	1333
Other including spare parts	KUS$	300	200	250	250
Total	KUS$	**2350**	**2075**	**5600**	**4658**

7.2.3 Space Requirements

The space requirements are most important in consideration of a platform based desalination system as the cost of platform space comes at a premium. One can envision locations where this technology is considered for commercial operations as a land-based system where one would find space requirements to be a key factor as well. Space requirements are given a weight of 20% of the standardized score due to the overwhelming impact this criterion has on multiple facets of the evaluation. Space requirements have a significant impact on capital cost and to a lesser extent, operating and maintenance costs, particularly for platform based systems. The importance of space requirements for land-based systems is due to cost and availability of land, cost of construction on certain types of land and the environmental impact of building on land in a given area.

7.2.4 Environmental Considerations

The environmental considerations are explained in detail in section 6. The weight given to the environmental standardized score is 10%. The cost to mitigate specific environmental impacts and the possibility of not being granted permits in some cases, as well as ethical concerns and public image considerations, cause the environmental criteria to be of significant importance.

7.2.5 Quality of Product

All of the alternatives considered are commercially proven to provide potable water that meets or exceeds national and international standards in commercial applications. MSF-VC and MED-VC generate a product with a considerably lower TDS level than do reverse osmosis plants. Taking into consideration that each of the alternatives produces a product of acceptable quality is the reason why this criterion is only given a weight of 5% of the standardized score.

7.2.6 Amount of Cold Seawater Required

The amount of cold seawater consumed is very significant for desalination systems associated with OTEC systems of the general design for which this study is being generated. The platform design is such that the cold seawater passes through the condenser units of the OTEC system far below sea level. To use the cold seawater in the desalination system after it has passed through the OTEC system would require the water be pumped back up to the platform deck incurring an elevation change of over 50 meters. The power required to do this would create an impractical solution for desalination. For MSF-VC and MED-VC systems, the thermodynamics of the process actually favor using the cold seawater prior to being warmed by the OTEC process, but this does not make up for the power requirements required in this configuration. Similarly, the reverse osmosis process favors the use of the cold seawater after being warmed by the OTEC process, but not to the extent that it would make sense to accept the additional power requirements of pumping the water up to overcome such elevation changes. The warm-SWRO process does not use the cold seawater.

The primary purpose of the OTEC system is power generation; the desalinated seawater is a secondary product of the system. Because the cold seawater used in the desalination processes is used prior to being used in the OTEC process, electricity generation is affected in a negative manner. In the case of the MSF and MED technologies, the cold seawater flow could be sent to the OTEC process after the desalination process, but the water would have an increased temperature in the realm of 5°C. Taken in consideration with the ratio of cold seawater used in the desalination process to the cold seawater used in the OTEC process, the temperature increase would cause a significant loss of power generation. In the case of cold-SWRO, if the cold seawater were sent back to the OTEC system after passing through the desalination system, there would not be much of a temperature gain, but there would be less cold seawater delivered to the condenser units. This would also result in less power generation.

The amount of cold seawater necessary for each desalination process in comparison to the amount necessary for the OTEC power generation is illustrated in Figure 7-1and Figure 7-2. It is also noteworthy that the 1 MGD seawater desalination system is being considered for operation with the 10 MW OTEC system and the 50 MGD seawater desalination system is being considered for operation with the 100 MW OTEC system. This means that for the respective configurations the cold seawater needs for desalination increase by a factor of 50 from small to large, but the cold seawater needs for power generation only increase by a factor of 10. This signifies a much greater impact on the power generation for the large system.

The MED-VC process uses nearly 25% of the cold seawater needed in the OTEC process for the 50 MGD / 100 MW system and just under 5% for the 1 MGD / 10 MW system. The MSF-VC process uses 44% of the cold seawater needed for OTEC in the larger system and almost 9% of that needed in the smaller system. Cold-SWRO uses less than 4% for the large system and less than 1% for the small. Also shown in Figure 7-1and Figure 7-2 is the amount of water for a MSF-VC research plant

built in India. The design for this system is different in significant ways from the design of the MSF-VC system from the Rabas [84] and Siah [64] reports, but this shows actual operating data from a working plant. The data taken from the reports show only theoretical data. That statement aside, it seems reasonable to assume that a MSF-VC plant could be built to follow a design as found in the reports that would provide data similar to those reported values.

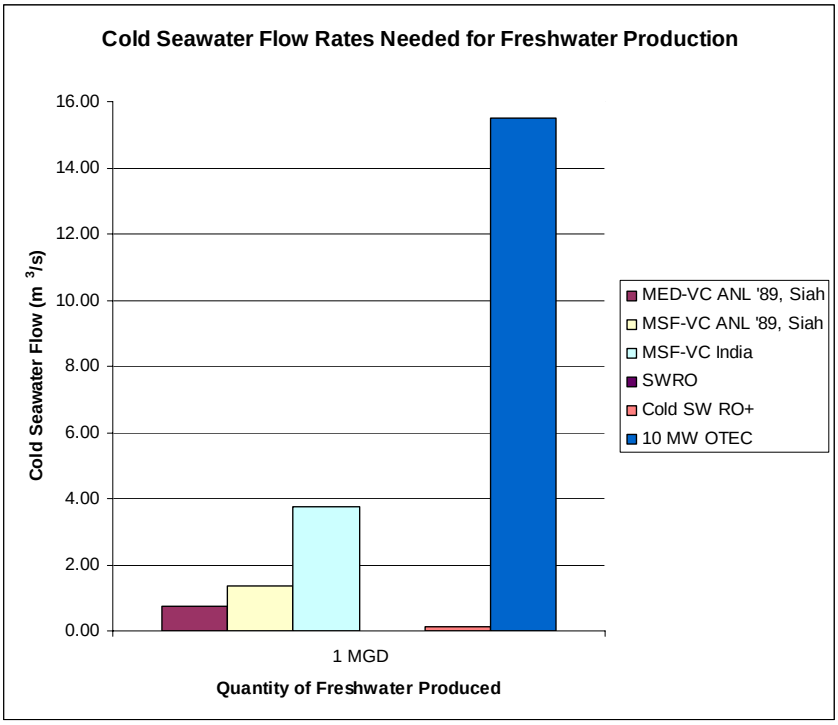


Figure 7-1 Cold Seawater Requirements for 1 MGD / 10 MW System

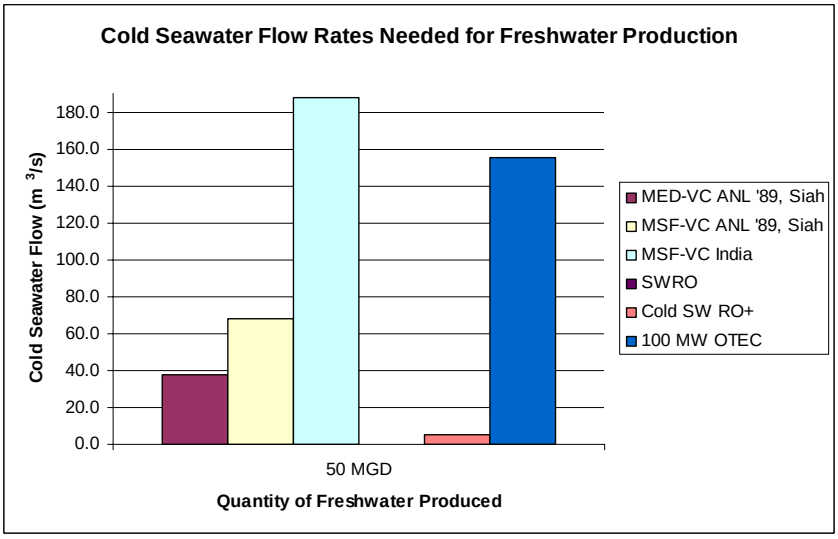


Figure 7-2 Cold Seawater Requirements for 50 MGD / 100 MW System

With all of the previously detailed effects on the overall system, cold seawater requirements are given the greatest weight for the standardized score in the MCDA of these alternatives of 25%. The cold seawater flow rates required for desalination for MED-VC and MSF-VC used in this study are the averages of those presented in the reports by Argonne National Laboratory [84] and Marc M. Siah & Associates [64]. The flow rates reported by the project in India are only shown for comparative purposes. The cold seawater flow rates used for the cold-SWRO are obtained from calculations based on warm-SWRO flow rates and temperature correction factors for SWRO desalination.

7.2.7 Electricity Consumption

The electricity consumption of each desalination technology is of great importance to the MCDA evaluation for much the same reason as the cold seawater requirements are important; the primary product is electricity. The secondary product is assumed to be of lesser value and therefore, consuming the primary product (electricity) to produce the secondary product (water) is counter-productive. That water production makes sense at all is due to situational circumstances: either there is great need for water at a certain time or location or electricity sales fluctuate and it is desired to maximize profit through water sales. Using more electricity than there is available as excess begins to deplete profit. For these reasons, electricity consumption is given a fairly high standardized score weight of 20%.

The electricity consumption, measured in kWh / m^3, does not include power required for distribution purposes. This would be the same for all technologies and not affect how they compare to one another. The electricity consumption for warm SWRO is derived from manufacturer and operating data gleaned from currently operating SWRO plants. For cold SWRO, electricity consumption was estimated based on the warm SWRO, temperature effects and known cold SWRO electrical demands for small-scale operations. MED-VC and MSF-VC are estimated from data for traditional MED and MSF plants and energy requirements for a vent compression system. MED and MSF processes both use a significant amount of thermal energy, which is not available in conjunction with the OTEC system. The electrical energy equivalent of the thermal energy is included in the respective electricity consumption values.

Table 7-2 Multi-criteria Decision Analysis Summary

	MED-VC				MSF - VC			
	Value	Weight	Score	Total	Value	Weight	Score	Total
Specific Capital Cost ($/m3/day)	1112	0.10	0.236	0.024	1183	0.10	0	0
O&M cost (kUS$ / year)	2075	0.10	1	0.1	2350	0.10	0.580	0.058
Space Required (m2/m3/day)	0.024	0.20	0.600	0.120	0.053	0.20	0	0
Environmental	30	0.10	0	0	28	0.10	0.067	0.007
Quality of Product (TDS)	15	0.05	1	0.05	15	0.05	0.965	0.048
Cold SW Required (m3/s)	37.6	0.25	0.448	0.112	68.1	0.25	0	0
Electricity Consumption (kWh/m3)	10.4	0.20	0.536	0.107	18.2	0.20	0	0
				0.513				**0.113**

	Warm SWRO				Cold SWRO			
	Value	Weight	Score	Total	Value	Weight	Score	Total
Specific Capital Cost ($/m3/day)	882	0.10	0.254	0.025	1167	0.10	0.013	0.001
O&M cost (kUS$ / year)	5600	0.10	0	0	4658	0.10	0.168	0.017
Space Required (m2/m3/day)	0.005	0.20	0.911	0.182	0.005	0.20	0.911	0.182
Environmental	20	0.10	0.333	0.033	20	0.10	0.333	0.033
Quality of Product (TDS)	425	0.05	0	0	425	0.05	0	0
Cold SW Required (m3/s)	0	0.25	1	0.250	12.1	0.25	0.822	0.206
Electricity Consumption (kWh/m3)	3.60	0.20	0.80	0.160	6.26	0.20	0.655	0.131
				0.651				**0.570**

8 DELIVERY METHODS

- Water bags, barges, tankers and pipelines considered
- Transportation of the water is very expensive
- Under current options, land-based systems with no platform to shore transport are favored

A platform-mounted desalination plant at sea will require a means to transport the potable water to shore economically. There are several methods that have been used in the past for commercial transport of fresh water across marine environments. These commercial options of transporting water to land include shuttling the water via a water bag, barge, tanker, or pipeline. This section will examine these options and their feasibility based on information and data available from commercial operations and recorded experience. The various technologies will also be compared under different production rates of 1 MGD and 50 MGD as well as distances from the plant to the shore of 5 km, 25 km, and 50 km.

8.1 Water Bag

Although not currently in commercial operation, transportation of product potable water in water bags is included in this evaluation due to the relative low cost and future potential of this option. The bags themselves are long cigar looking vessels that are made out of polyester fabric that is coated in a layer of plastic. Figure 8-1 shows a photograph of a water bag during the towing operation. Because of the difference in densities between seawater and freshwater, the bag will float and can be towed by a tugboat to a port or offloading site at the coast. The commercial capacity of these bags ranges from 750 m^3 (approximately 200,000 gallons) to 17,000 m^3 (approximately 4.5 million gallons) [7]. However, the larger bags are not in commercial use and the companies operating them, such as Nordic Water Supply, have not been successful or profitable in operation due to the susceptibility to tears of the bag material and potential for loss at sea during ocean transport over distance [19]. According to the manufacturer, each water bag has an average life expectancy of 10 years. The largest commercial-sized bags can hold up to 4,500,000 gallons each and can be tethered together to form multiple bags in a train for larger capacity delivery.

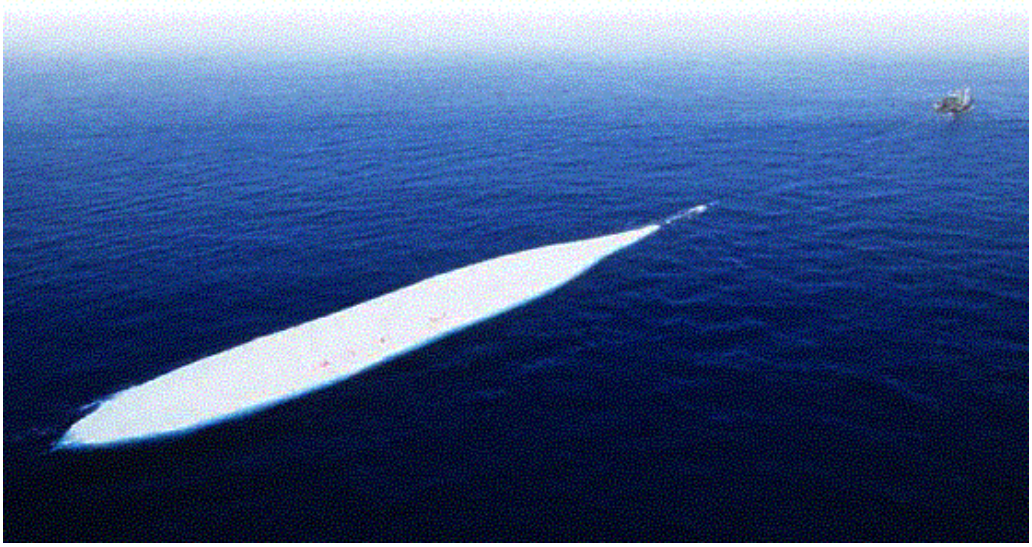


Figure 8-1 Photograph of large water bag under tow

The associated costs of the minimum and maximum number of bags that could successfully bring the water to shore from 50 km, 25 km, and 5 km for production levels of 50 MGD and 1 MGD were examined. Capital costs and O&M costs are provided for all alternatives examined in Appendix A.

A minimum of 27 bags is necessary to transport 50 MGD from a platform located 50 km from the delivery site (100 km round trip). This amount accounts for the time required for the tugboat to bring the bags to the delivery location at a speed of 3 knots (maximum towing speed of bags in the ocean) and return at a speed of 10 knots [92]. These speed constraints as well as an offload time that was 1.8 times faster than the loading time (set by the production limits of the desalination system) yield a round trip duration of 27 hours. By using the largest bags available from the manufacturer of 4.5 million gallons, 27 bags minimum would be required. This accounts for 13 bags per trip and an extra water bag stored at the loading facility. The corresponding capital investment would be approximately $10.8 million with unit bag cost of $400,000 [92]. This represents the only capital cost for this delivery method. The delivery tugs are chartered in this example and considered in the operations cost. The facilities for loading and delivery are assumed costs external to delivery.

In a similar fashion, minimum requirements for distances of 50 km round trip and 10 km round trip were calculated. The results concluded that a minimum number of 15 bags are required for the 50 km roundtrip journey and a minimum of five bags are required for the 10 km roundtrip. These minimum capital costs are $12.25 million and $8.25 million respectively.

For 1 MGD production, the same sized bags were used with a minimum of three bags total for all three distances of 50 km, 25 km and 5 km. This simplification was possible because each bag holds about 4.5 days of water production, more than enough time for the tug to make the round trip with the water bags and pick up the next batch at the distances considered. The minimum capital investment for the three bags is $7.45 million.

Operation and maintenance costs for the 100 km round trip 50 MGD were calculated based on costs of fuel, tug crew salaries, deck crew salaries, tug boat insurance at 2% of capital cost, tug boat maintenance, bag repair costs and an added 1% for miscellaneous costs [92]. The fuel costs were calculated for the tug by using $3.50 / gal for the cost of the diesel fuel required [92]. The amount of fuel required for a tug boat for each trip was based on the fuel requirements for the tug boats in the 300-mile trip in Spragg's [92] economic analysis. The number of trips was calculated by the 330 days of expected operation divided by the time it would take for each round trip. The salaries for the tug boat crew came out to be $1 million per crew, which would be doubled since two crews are necessary to operate the tug boat as often as the production rate would require. For 50 MGD two crews are necessary to operate all day while for 1 MGD only one crew is necessary as the boat is not running every day [35]. The loading dock crew salaries came out to be about $400,000 for the two workers that would cost approximately $200,000 each [35]. The total cost of bag repair annually is expected to be $10,000 according to the manufacturer.

Although these bags are not commercially in use today, it is possible that in the future they will play a bigger role in fresh water transportation. Under the parameters established for this investigation of only considering commercially viable technologies, water bags are not considered further.

8.2 Barge

Barges have been used to transport water commercially for many years. During times of drought, Puerto Rico has periodically barged water into the U.S. Virgin Islands. In 1985 the delivery cost was approximately $4.65 per m^3 ($9.42 in 2010 dollars). According to Global Water Intelligence, Bahamas Water and Sewerage Corporation has shipped water on several barges (transporting about 20,000 m^3/day or 5.3 MGD) over a distance of 60 km between Andros Island and New Providence [11]. The price for transporting this water via barges in 1997 was approximately $3.41 per 1,000 gallons including fuel costs ($4.63 in 2010 dollars), and about $5.41 per 1,000 gallons factoring in the costs of the receiving and delivery facilities required on each island ($7.35 in 2010 dollars). This equates to about $1.22 / m^3 without the costs of shipping facilities and $1.94 / m^3 with facility costs, in 2010 dollars. Due to scheduled and unscheduled maintenance requirements and weather concerns, the barges in the Bahamas averaged 25 days per year of operation disruption. To improve the economics associated with this delivery, the Bahamas have since converted operations from barges to tankers.

The transportation of 50 MGD of potable water was analyzed assuming the costs for new barges owned by the desalination facility. Under the system design conditions, depending on the distance of the trip, two or three barges would need to be purchased, along with either one or two tugboats to bring them back and forth. Because the tug is limited to 10 knots towing 16.8 million gallons in each barge over a 50 km delivery route, three barges would be required for each day's delivery, as well as two tugboats. While the first tugboat brings one load to the delivery location from the production platform the next barge can be loaded ensuring continuous production and delivery of product water. The third barge could then be filled as the second tugboat takes the second barge away, and the first tugboat would arrive back in time to pick up the third.

Around 25 km is the threshold when only two barges would be needed to guarantee giving enough time for just one tugboat to get back to switch barges. For 1 MGD production levels, only two barges with 1.26 million gallon capacity would be needed along with a tugboat of lower horsepower. Capital costs for this scenario included these tug boats and barges, as well as moorings, connecting pipes and an offshore pipeline to ship the water to shore. The full list of costs can be seen in Appendix A.

Annual operation and maintenance costs for these scenarios consist of fuel costs, tug crew salaries, deck crew salaries, tug and barge insurance, as well as maintenance for the tug, barge, and pipeline. An added 1% miscellaneous charge was added for unforeseen costs of the operation. The full array of O&M costs can also be seen in Appendix A.

All costs for the barge alternative were obtained from budget quotes from barge designers and from a study performed by the Turkish government on water transportation between Turkey and Cyprus [9].

The cost of transporting the water via barges is enormous for the 50 MGD production levels because it requires new barges to be constructed bigger than any commercially available. For the smaller production levels, there are commercially operating barges and tows that can more than meet the levels of production demanded.

8.3 Tanker

Tankers are another possibility to transport either the 1 MGD or 50 MGD of product water from the offshore desalination plant to its delivery location. Different sized tankers would be required, and are available, depending upon the production capacity. To service the 50 MGD production level, tanker

options include either three smaller 40,000 m^3 capacity tankers, or two larger capacity tankers. The analyses in this study are based on the 40,000 m^3 capacity tankers. The 40,000 m^3 tankers reportedly travel at an average speed of 20.8 km/h [9]. With an estimated five hours required to fill a 40,000 m^3 tanker at a production level of 50 MGD, and assuming a 3-hour offloading and turnaround time, the desalination plant could be successfully serviced by three such tankers over a platform to shore delivery distance of 50 km.

The capital and annual O&M costs of the tankers were calculated for scenarios placing the desalination plant 50 km from shore, 25 km from shore, and 5 km from shore. For both the 50 km and 25 km examples at 50 MGD of production, three tankers of 40,000 m^3 capacity were required to maintain constant production. At 5 km, only two tankers are required. For 1 MGD production levels, only two tankers of 40,000 m^3 are required at all distances. The capital costs for each scenario consist of the cost of the tankers themselves, as well as the installation of a mooring system and its connection pipes, as well as a 1.5 km underwater pipeline to transport the water from the delivery location (mooring) to the shore connection. Thus the only varying factor in each example, regardless of production level or distance from shore, is the number of tankers which make total capital costs either $19,375,000 or $27,375,000 for 2 or 3 tankers respectively.

Annual O&M costs were calculated for each scenario to include the salaries of tanker workers and loading deck crews, as well as tanker maintenance costs, tanker insurance, fuel costs and pipeline maintenance. Tanker crew salaries, maintenance costs, and insurance all varied depending on the number of tankers in the specific example. Fuel costs were calculated based on fuel requirements for the 40,000 m^3 capacity tankers from a case study involving the transportation of bulk water via tanker from Turkey to North Cyprus [9]. Fuel costs included that of fuel oil at $150/ton and that of diesel oil at $220/ton. These numbers varied based on the number of tankers, trips taken per year, and distance traveled by the tankers. An added 1% of miscellaneous maintenance costs were included. The full array of operation and maintenance costs and capital costs can be seen in Appendix A. All costs for tankers were obtained from budget quotes given by tanker design engineers and from a study performed by the Turkish government on water transportation between Turkey and Cyprus [9].

8.4 Pipeline

The fourth option considered for transporting the water from the platform-based production system to a land-based distribution system is a marine pipeline. As with the previous transport methods, the pipeline was investigated for 1 MGD and 50 MGD production levels at distances of 5 km, 25 km and 50 km. The pipeline system data is based on reported values from a project in the Mediterranean Sea where potable water is transported from Turkey to Cyprus [9]. The pipeline is suspended by buoys at a depth of 250 m in the crossing from Turkey to Cyprus. The Turkey – Cyprus pipeline serviceable capacity is slightly larger (approximately 54 MGD) than the largest production capacity considered for this study (50 MGD) at a delivery distance of 77 km. The cost estimate for the pipeline in the Turkey-Cyprus project supports cost estimates used for the pipelines in this study. Pipelines in this study are estimated using budget quotes for previous projects and known costs of constructed projects. Annual pumping costs assume an electricity rate of $0.20 / kWh. Table 8-1 and Table 8-2 show a summary of the relevant power requirements and costs associated with the various pipeline transport alternatives.

Table 8-1 Pipeline Transport Summary for 1 MGD Capacity

1 MGD			
Pipeline distance	5 km	25 km	50 km
Flow rate	0.0438 m^3 / s	0.0438 m^3 / s	0.0438 m^3 / s
Pump head	105 m	525 m	1050 m
Power requirement	60 kW	300 kW	590 kW
Pipeline cost	$ 7,213,800	$ 36,069,018	$ 72,138,037
Pump cost *			
Annual pumping cost	$ 95,537	$ 476,865	$ 953,526

Table 8-2 Pipeline Transport Summary for 50 MGD Capacity

50 MGD			
Pipeline distance	5 km	25 km	50 km
Flow rate	2.19 m3 / s	2.19 m3 / s	2.19 m3 / s
Pump head	15 m	72 m	143 m
Power requirement	410 kW	2010 kW	4010 kW
Pipeline cost	$ 3,288,330	$116,441,649	$232,883,298
Pump cost *			
Annual pumping cost	$ 660,918	$ 3,252,727	$ 6,492,488

***Budget quotes for the capital costs of the various pumps were requested from multiple vendors but were not obtained by the end of this study. Compared with the capital cost of the pipelines and the additional operating cost to run the pumps, the capital cost of the pumps themselves would likely have little effect on the results of this study.

9 ECONOMICS

- Land-based systems more economical than platform-based
- Costs based on budget quotes obtained from manufacturers
- Not cost competitive in US markets, but might be in the future

After determining the best seawater desalination process for coupling with an OTEC system to be reverse osmosis, a life-cycle cost analysis was performed for both land-based and offshore platform-based SWRO systems. Financial parameters were held constant while production capacity and location of the SWRO system were varied as they were throughout the study: 1 MGD potable water production, 50 MGD potable water production for both land-based and platform-based systems.

9.1 Capital Cost

The capital cost for the seawater reverse osmosis (SWRO) desalination system is derived from quotes obtained for previous projects. These quotes more closely represent the 1 MGD system, but yield a conservative cost estimate for the 50 MGD system as there is likely an economy of scale which could be realized during system design. The quotes used provide cost estimates for seawater supply pumps and piping, the pre-filtration system, the SWRO system, buffer tanks, brine discharge pumps, piping. The cost of deck space on the platform to house the equipment is derived from a formula provide by The Glosten Associates for rough order of magnitude estimates. The estimates consider space and weight requirements of the desalination equipment (estimates based on information from equipment manufacturers) and their affect on platform buoyancy as well as square footage requirements. Table 9-1 shows the capital cost breakdown for both the 1 MGD and 50 MGD systems. The economic analyses performed for a platform based system do not include the cost of product delivery. The analyses performed for land-based systems do not include the cost of land, as the site for the project is undetermined and land costs vary widely by location. When looking at the cost of additional platform space compared to the cost of land in most areas, it is apparent that land-based systems are more economical. When transport costs from platform to shore are considered, this is even more apparent. These elements that have been left out of the economic analysis are discussed further throughout this section.

Table 9-1 Seawater Reverse Osmosis System Capital Costs

System Capacity	1 MGD	50 MGD
Seawater supply pumps	$ 86,250	$ 1,437,500
Supply piping	$ 8,056	$ 99,142
Pre-filtration system	$ 949,630	$ 47,481,511
SWRO system	$ 1,901,063	$ 93,035,411
Buffer tanks	$ 63,825	$ 1,380,000
Discharge piping	$ 13,426	$ 164,346
Brine discharge pumps	$ 51,750	$ 690,000
Platform deck space	$ 3,205,762	$ 133,038,657
Total for platform-based option	**$ 6,279,761**	**$ 277,326,567**
Total for land-based option	**$ 3,073,999**	**$ 144,287,910**

9.2 Operation & Maintenance Cost

Operation and maintenance costs were provided by the manufacturer of the SWRO system. The O&M cost comprises three main categories: electricity usage, membrane replacement and general system maintenance. The O&M costs do not include product delivery or platform maintenance. The electricity usage is based on an efficiency obtained from operations data of actual facilities of 14.4 kWh per kgal (3.8 kWh / m^3) of fresh water produced and a utilization rate of 90%. The membrane replacement cost is provided by the manufacturer as $800 per membrane and each membrane being replaced on average once every three years. General system maintenance cost is provided by the manufacturer as $0.46 / kgal of water produced. These parameters are taken from known operating data. Table 9-2 gives a breakdown of the operating and maintenance costs for the 1 MGD and 50 MGD systems. The table represents the first year operation and maintenance costs for the systems. The O&M costs are assumed to escalate in each subsequent year by a factor of 3% for membrane replacement and general maintenance and a rate of 3.76% for electricity costs.

Table 9-2 Seawater Reverse Osmosis System Operation and Maintenance Costs

System Capacity	1 MGD	50 MGD
Electricity cost	$ 946,728	$ 47,336,400
Membrane replacement	$ 96,000	$ 3,840,000
General maintenance	$ 151,121	$ 7,560,675
Total	**$ 1,193,849**	**$ 58,737,075**

When delivery costs are factored into the O&M cost for platform-based systems the increase varies for different scenarios of the alternatives examined. The cost of each of the four alternatives was estimated for platforms located 50 km, 25 km and 5 km offshore. The findings for transporting water via each of the alternatives from each of the three distances are discussed below.

For the 1 MGD production capacity, the transport costs exceed the production costs for all four methods at all three distances. This clearly displays the economic benefits of a land-based system over platform-based production and transporting the water to shore. It is unlikely that there would be any situation where a platform-based 1 MGD production facility coupled with delivery to shore would be preferred over a land-based system unless external environmental restraints are imposed.

For the 50 MGD production capacity the outcome is slightly different and is described below. Land-based production is still favored in most cases, but there are some scenarios that could be practical.

Transporting water from 50 km offshore

- The O&M costs increase by 50% or greater for tankers or barges. The capital cost of the transport systems is very significant for both tankers and barges. The total cost for these transport mechanisms at 50 km distance further drives the cost of water production for a platform-based system beyond what can be supported by any US market.

- The use of a pipeline from this distance would increase the capital cost of the project by over 80% and increase the operating cost by over 10%. Again, this drives the price too high for this method to compete with a land-based system.

- The use of water bags has the least impact of cost with less than a 10% capital cost increase and about 6% O&M cost increase. However, the use of water bags has not been proven commercially successful. The water bags might prove a viable option in the future.

Transporting water from 25 km offshore

- For barges and tankers, the O&M costs still increase by greater than 50%, resulting in too high of costs for this to be considered a viable option under present economic conditions.

- The 25 km pipeline would increase the capital cost by over 40% and operating costs by over 5%. Again, the $116 million cost of the pipeline cannot compete with the cost of land for a land-based system.

- The use of water bags is again the most economical option for transporting a distance of 25 km, but the cost savings is not as great as it was for the 50 km distance.

Transporting water from 5 km offshore

- The O&M cost for tankers and barges increases by approximately 30% for the 5 km distance. This is still a significant price increase, but a substantial improvement over the farther distances.

- Transporting 50 MGD via pipeline over a distance of 5 km does not add too much cost to the platform-based production system. The additional cost to maintain a 15% IRR as calculated without the transport costs included is only about 3% greater.

- Using water bags to transport the water from 5 km is more expensive than the pipeline and, again, is not commercially viable at this time.

9.3 Life Cycle Cost Analysis

The life cycle cost analysis of the water production system is affected by several factors, including financing terms and the economics of the OTEC facility itself. With a limited design for both the OTEC system and RO system, certain assumptions have been made in an effort to create a foundation of consistency for the economic analyses of the water production systems. These assumptions form the basis of the life cycle cost analyses and are given in Table 9-3.

Table 9-3 Life Cycle Cost Assumptions

Life Cycle Cost Analysis Assumptions	
% Equity Financing	20%
% Debt Financing	80%
Debt recovery interest rate	8%
Price escalation rate	3%
System operability rate	90%
System efficiency	14.4 kWh / m^3
Electricity rate	$ 0.20 / kWh
Project life	25 years

The above assumptions are held constant while varying the first year sale price of the water and performing a cash flow analysis at each price. The sale price is escalated at a rate of 3% per year throughout the life of the project. Depreciation, interest during construction and salvage values are not included in this basic economic analysis. The outputs are all reported before taxes and include: internal rate of return, simple payback period and return on investment for 10, 20 and 25 year project lives. The life cycle cost assumptions hold constant for both land-based and platform-based systems.

The initial sale prices were chosen by using an IRR of 15% as a baseline. The result for the platform-based systems is a baseline initial sale price of $5.347 / kgal for the 1 MGD system and $5.101 / kgal for the 50 MGD system. The sensitivity of the various metrics to the initial sale price was assessed by running the economic analysis at prices of 10%, 20% and 30% higher and 5% lower than the baseline price. A summary of the results is shown in Table 9-4 and Table 9-5.

Table 9-4 Summary of Economic Metrics for Platform-based 1 MGD System

	Price / kgal	Avg. Price	IRR	10 yr ROI	20 yr ROI	25 yr ROI	Payback
-5%	$ 5.080	$ 7.408	8.4%	10%	46%	73%	NA
Baseline	$ 5.347	$ 7.798	15.0%	27%	83%	124%	23 years
10%	$ 5.882	$ 8.578	27.6%	59%	159%	226%	15 years
20%	$ 6.416	$ 9.357	40.7%	91%	234%	328%	11 years
30%	$ 6.951	$ 10.137	54.1%	123%	309%	430%	9 years

Table 9-5 Summary of Economic Metrics for Platform-based 50 MGD System

	Price / kgal	Avg. Price	IRR	10 yr ROI	20 yr ROI	25 yr ROI	Payback
-5%	$ 4.846	$ 7.067	7.7%	9%	42%	66%	NA
Baseline	$ 5.101	$ 7.439	15.0%	27%	82%	121%	23 years
10%	$ 5.611	$ 8.183	28.8%	61%	164%	231%	15 years
20%	$ 6.121	$ 8.927	43.0%	96%	245%	342%	11 years
30%	$ 6.631	$ 9.671	57.6%	131%	326%	452%	8 years

The same process was repeated for the land-based systems as for the platform-based systems of finding initial sale prices that would yield a 15% IRR. The baseline prices calculated were $4.492 / kgal for the 1 MGD land-based system and $4.392 for the 50 MGD land-based system. A summary of the results from the economic analyses for the land-based systems is shown in Table 9-6 and Table 9-7.

Table 9-6 Summary of Economic Metrics for Land-based 1 MGD System

	Price / kgal	Avg. Price	IRR	10 yr ROI	20 yr ROI	25 yr ROI	Payback
-5%	$ 4.267	$ 6.223	1.6%	0%	16%	28%	NA
baseline	$ 4.492	$ 6.551	15.0%	27%	81%	115%	23 years
10%	$ 4.941	$ 7.206	37.4%	83%	210%	290%	12 years
20%	$ 5.390	$ 7.861	60.6%	138%	339%	465%	8 years
30%	$ 5.840	$ 8.517	84.3%	193%	468%	641%	6 years

Table 9-7 Summary of Economic Metrics for 50 MGD Land-based System

	Price / kgal	Avg. Price	IRR	10 yr ROI	20 yr ROI	25 yr ROI	Payback
-5%	$ 4.172	$ 6.084	NA	NA	12%	19%	NA
Baseline	$ 4.392	$ 6.405	15.0%	28%	79%	111%	24 years
10%	$ 4.831	$ 7.045	38.7%	85%	213%	293%	12 years
20%	$ 5.270	$ 7.686	63.0%	143%	348%	475%	8 years
30%	$ 5.710	$ 8.327	87.7%	200%	482%	658%	6 years

The four economic summary tables are explained in the following manner. The price / kgal column shows the initial price for the water. This price is escalated at 3% per year each year of the project to recover inflationary costs. The average price column shows the average price for the water over the 25 year project. The IRR shown is based on the equity portion (20%) of the project capital cost and the annual cash flow. This is illustrated further in Figure 9-1. The return on investment and simple payback metrics are based on the total project capital cost and the annual cash flows. The return on investment data is illustrated in Figure 9-2, Figure 9-3, Figure 9-4 and Figure 9-5. The simple payback period for the initial sale price 5% below the baseline is listed as NA because the payback would not occur within the 25 year project life for either project. The other payback periods are rounded up to the nearest whole year.

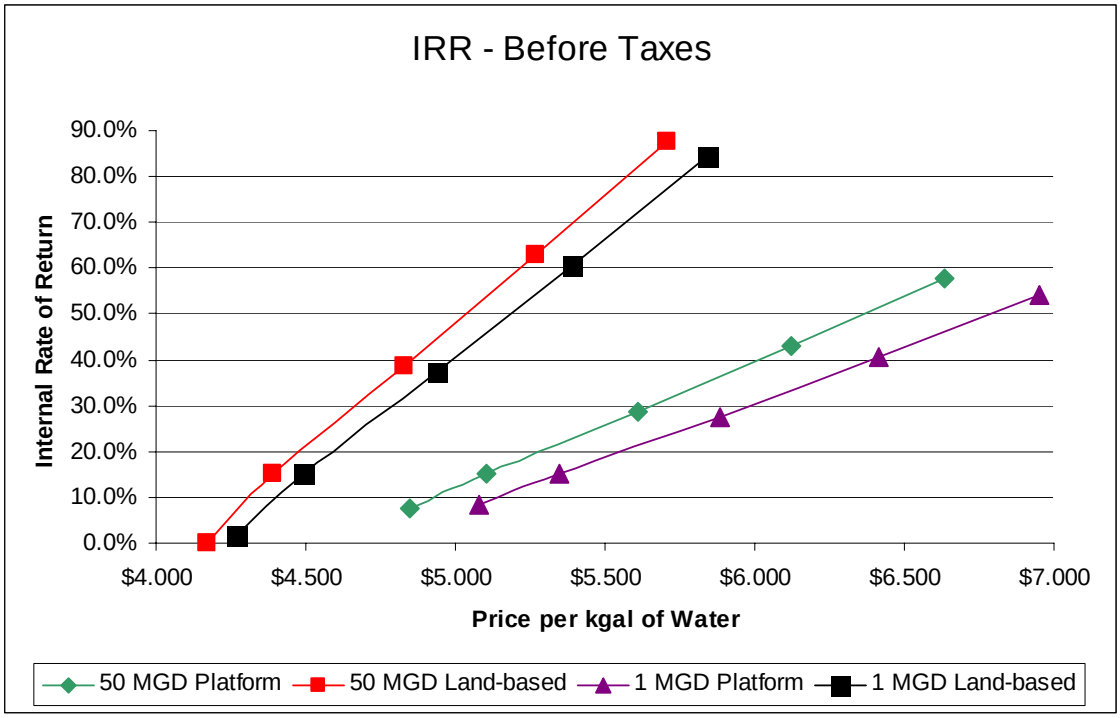


Figure 9-1 IRR for Each Alternative at Various First Year Sale Prices

As shown in Figure 9-1, the IRR increases most rapidly for the land-based systems. This is due to the high cost of additional platform space necessary for the water production systems. The 50 MGD system yields higher returns than the 1 MGD system in either land-based or platform-based operations, showing an economy of scale benefiting large-scale operations. This is concurrent with the literature reviewed in this study. As would be expected, results of the cumulative ROI data follow the same pattern.

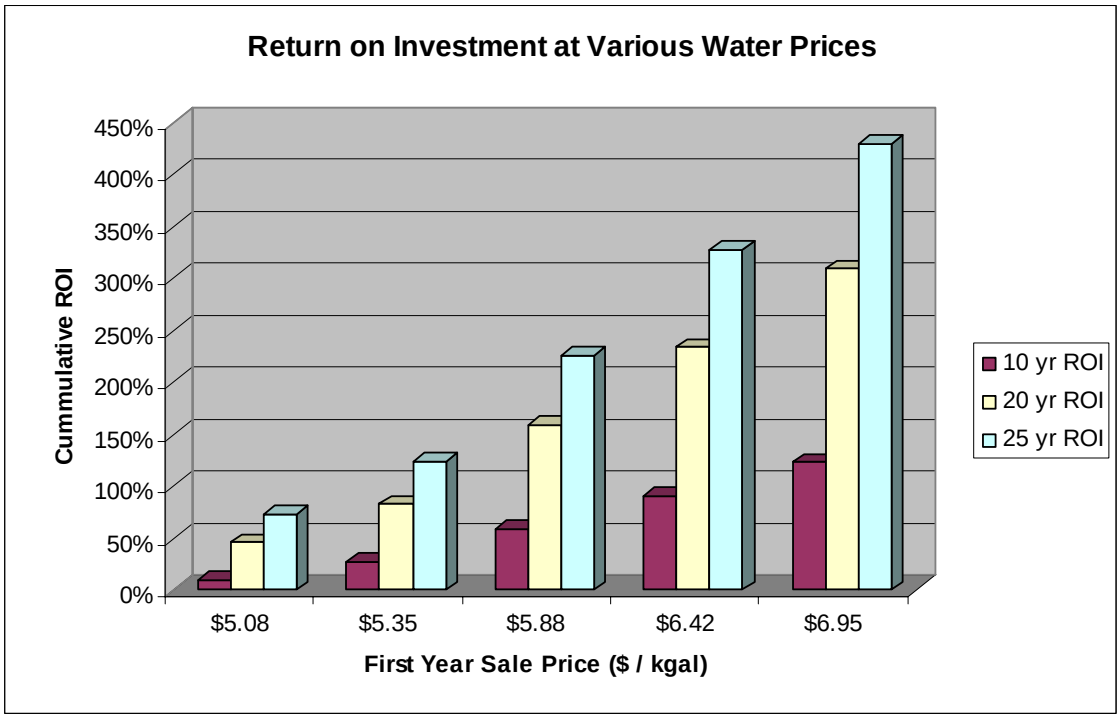


Figure 9-2 ROI for Platform-based 1 MGD System at Various First Year Sale Prices

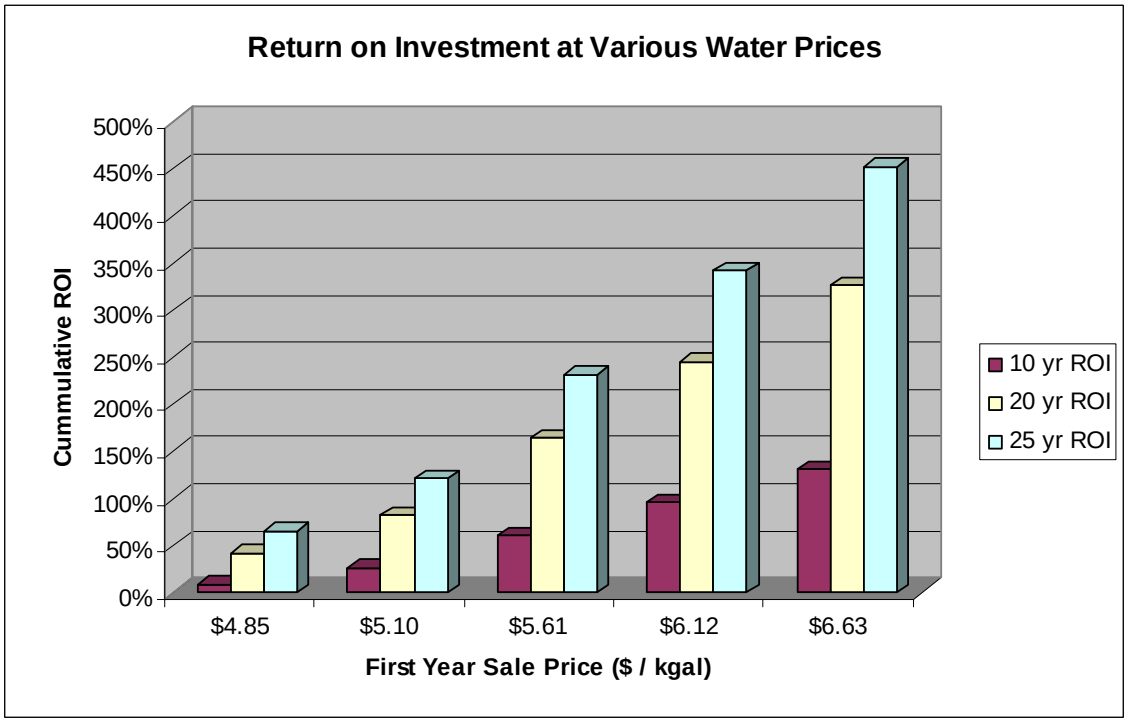


Figure 9-3 ROI for Platform-based 50 MGD System at Various First Year Sale Prices

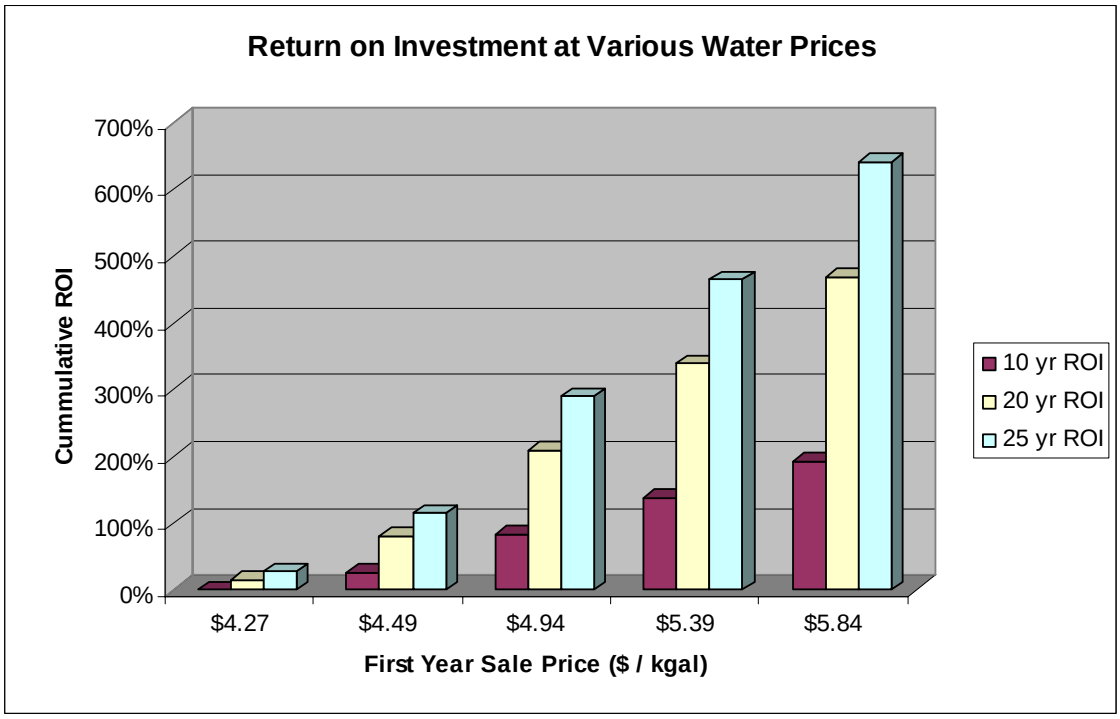


Figure 9-4 ROI for Land-based 1 MGD System at Various First Year Sale Prices

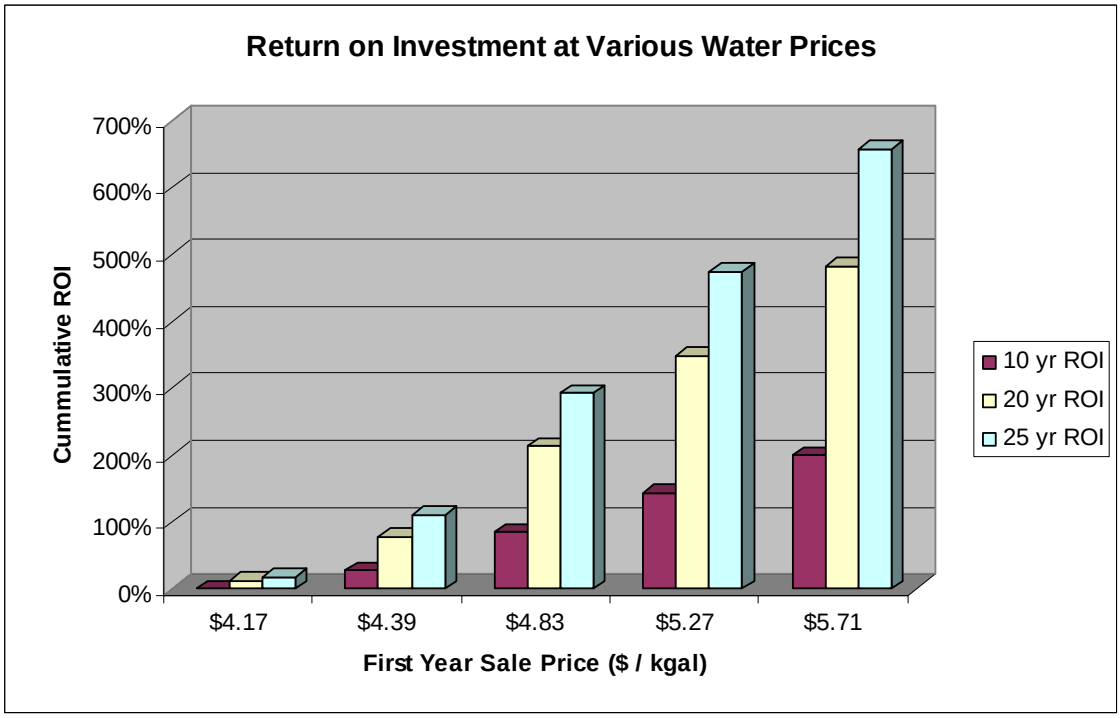


Figure 9-5 ROI for Land-based 50 MGD System at Various First Year Sale Prices

10 RISK ANALYSIS

- Reverse osmosis units have a proven track record of reliability
- Component redundancy throughout the system mitigates risk
- More detailed risk analysis once design is complete

10.1 Components

The main components of a reverse osmosis plant include high pressure stainless steel piping and valves, stainless steel centrifugal pumps, programmable logic control (PLC), an antiscalant system, a clean in place (CIP) system, and reverse osmosis membranes. Feedwater supply lines, effluent discharge lines, product delivery lines, and pre-filtration systems are also required, but will vary depending on the location of the plant and quality of source seawater. The structure of the plant itself may also vary with location.

The primary components will remain the same regardless of location of the plant. Piping is resistant to corrosion from seawater and is 904L SS. High pressure valves are 316L SS. Duplex SS centrifugal pumps are used to supply the feedwater. The PLC, antiscalant system, CIP system, and reverse osmosis membranes all remain unchanged. The PLC monitors the RO process and keeps it running at optimal conditions. Antiscalant is used to prevent hardening of the membranes and to extend the time between cleaning cycles. The CIP system is an automated cleaning system that expedites the cleaning process and extends the life of the membranes. The RO membranes used in this analysis are 8 inch by 40 inch thin film composite (TFC) membranes that exhibit high salt rejection rates.

A shore based RO plant would require piping for both seawater supply and discharge of the briny effluent. The seawater supply pipe would require approximately 87,000 gpm of seawater for the 50 MGD system. This results in a pipe of approximately 1.7 meters in diameter that would draw seawater from the open ocean and deliver it to the RO plant. The open ocean feed requires a pre-filtration system to prevent RO membrane damage or clogging. It will also help reduce biofouling within the RO process. The discharge pipe would require a diameter of approximately 1.3 meters if running at the same flow velocity of the supply pipe of 2.5 m/s. The potable water product would be pumped into storage / buffer tanks before entering the municipal supply, tanker trucks or other distribution system.

Placing the RO plant on the OTEC platform allows for the supply and return piping to be more integrated with that of the OTEC system. It also reduces the number of pipes required for shore crossing in the coastal / reef areas. It does, however, require a more complicated means of delivering the water to the distribution system. This may be done via pipeline, tanker or barge or through the use of water bags towed to the land-based distribution system. These options are discussed in more detail in section 8 of this report. The feedwater supply for the RO unit should be drawn from the surface water whether platform-mounted or land-based desalination is preferred. The effluent RO discharge should be piped into the OTEC discharge pipe for a platform-based RO system or will require a typical outfall pipe if land-based.

10.2 Integration of the Reverse Osmosis Unit with the OTEC System

For a land-based RO system, there is no real integration with the OTEC system. The only connection between the two is that the power required for the RO system is supplied by the OTEC facility.

Packaged RO systems are ideal for integration with the OTEC platform for the 1 MGD system and could potentially be used for the 50 MGD system. Whether they are skidded units or placed in standard shipping containers, the components can be easily incorporated into the design of the platform. The low space requirements and ease of expandability are key benefits of using an RO system to produce potable water on a floating platform. The packaged systems are optimized to limit energy usage and require approximately 13 - 15 kWh / kgal. Approximately 27 MW of electricity production from the OTEC system will be used to run the 50 MGD reverse osmosis potable water production plant and 540 kW for the 1 MGD plant.

The platform mounted reverse osmosis system will draw seawater from independent lines used solely for the RO plant. The seawater will run through the reverse osmosis process and the output of each container will be combined into one product. The product stream of the RO units is collected in holding tanks and transferred to the potable water distribution system that is discussed in the delivery section of this report. The holding tanks on the platform serve as a buffer between the RO system and the delivery system as protection against contamination of the product and to provide minimal storage for start-up and shut-down operational requirements.

10.3 Risk and Reliability

Maintenance of the RO system includes routine maintenance of pumps, valves, piping, and other typical pieces of equipment. It also involves periodic cleaning and replacement of the separation membranes. The 50 MGD RO unit will have roughly 14,400 separation membranes. Under normal operating conditions, it is expected that the membranes will need replacement once every three years. Membrane replacement is the most significant portion of the maintenance requirements; however, it is accomplished with limited labor and on a known schedule, thus limiting system downtime. The system is expected to operate at least 90% of the time on an annual basis. No dedicated personnel are needed for the 1 MGD RO system. The maintenance requirements for the RO system can be met by the general personnel employed for the OTEC system. In the case of the 50 MGD RO system, there will be a need for additional personnel due solely to the large number of membranes. The relative simplicity of the system allows for minimal maintenance issues. This provides for optimal runtime for the water production plant.

A risk analysis of the water production system can be used to determine the availability of the system through reliability engineering.

Availability is a key measure of system performance and is defined as the fraction of time that a system is functioning. Availability is measured as the ratio of uptime to total time, or MTBF/(MTBF+MTTR), where MTBF is the mean time between failures and MTTR is the mean time to repair. *Inherent availability* refers to the time the system works, where the downtime is solely made up of active repair or maintenance time. *Operational availability* adds logistic factors, such as spare parts delivery and repair team schedule, to the downtime.

Reliability is a representation of the failure rate of components or the system as a whole and is typically given as the number of failures over a period of time. Reliability is improved through *Redundancy*, the inclusion of additional components to perform the work when the primary component is down for maintenance or repair. A system in *Active Redundancy* has extra components that are working together with the primary components. *m*-out-of-*n* active redundancy refers to *n* components running, while only *m* are necessary to perform the work. In s*tandby redundancy*, a

backup component is switched on when the primary is taken out of service. When the primary component is returned to service, the backup component is switched off.

Estimations of availability and reliability of the water production system are necessary to determine system production. While 100% reliability is impossible to achieve, system reliability can be improved with component redundancy and a good maintenance schedule. Redundancy is designed into the system to limit the effects of component malfunction and p*reventive maintenance* will identify and correct problems before they lead to failure. While more redundancy and frequent maintenance increase operational availability, these come with associated costs that must be factored into the system cost; at some point, the additional cost of redundancy becomes greater than the value of the increment of availability.

The water production system includes redundant components where determined to be necessary. Providing redundancy to certain system components, however, is not practical. These components, which include the seawater intake and effluent pipes, platform space other than that used to store primary and redundant systems, and the product transmission pipe, are assumed to have reliabilities of 100%. Additionally, the system will be sufficiently staffed such that human error will have a negligible effect on system reliability.

The reliability of the system can be assessed by constructing a Reliability Block Diagram (RBD). A chart of the component interconnections is drawn and reliabilities of components or systems of components are shown. Reliability of a system of components is calculated using standby redundancy, active redundancy, or no redundancy. Systems of parallel components are resolved into series and the overall system reliability is found by multiplying the reliabilities.

A Reliability Block Diagram of the water production system is presented in Figure 10-1. A number of the components in the RBD are of unique design and therefore do not have performance data, such as MTTF, associated with them. Additionally, prohibitive costs prevent redundancy of some components. The platform and the cold water pipe for the OTEC system are two of these components and are taken as having infinite lifespans for this exercise. This does not assure that neither will fail. Rather, a failure in either of these components would be catastrophic to the efficacy of the desalination process. The product transmission pipe (or selected distribution option) is given an infinite lifetime, however, its loss would not necessarily be a catastrophe to desalination system operations.

The OTEC system has its own reliability and associated maintenance and downtime. The water production system will not operate during the OTEC system downtime. A fully-redundant OTEC system is not possible, but this is not expected to limit the productivity of the RO system.

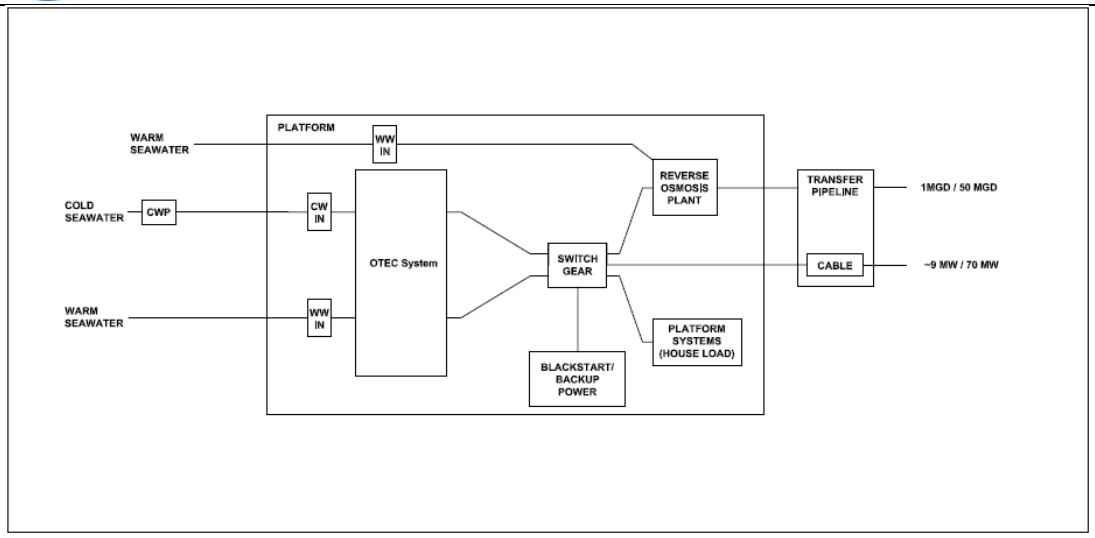


Figure 10-1. Water Production System Reliability Block Diagram.

The power generated by the OTEC system, which will be used to drive the RO process, is derived from the utilization of the Rankine cycle. The Rankine cycle is very commonly used and has a high level of availability; however, we cannot place a value on the availability until the final design has been completed.

The reverse osmosis water plant maintenance covers pumps, valves, piping, and other typical pieces of equipment, as well as periodic cleaning and replacement of the roughly 14,400 separation membranes. Under normal operating conditions, membrane replacement is expected every three years. Labor will be minimal and will be performed on a known schedule. The system will remain operational at a slightly reduced capacity during membrane replacement.

More specific details about the components will be known when the final design for both the OTEC system and RO process are completed. Performance parameters will be used at that time to further quantify risk and availability.

11 CONCLUSIONS AND RECOMMENDATIONS

- Vent compression used with MSF and MED consumes too much water prior to use in OTEC system under current Lockheed design
- Land-based SWRO with power cabled to shore determined to be best fit

There are several potential methods to desalinate seawater. The most common and those that show the most potential were examined during a thorough literature search. Of these processes examined, three were determined to meet the minimum requirements necessary for consideration of being used in conjunction with an OTEC system. The three processes chosen for further evaluation were MED, MSF and reverse osmosis. They were chosen because they were the only seawater desalination technologies that were commercially viable at production capacities of up to 50 MGD. MED and MSF were evaluated in conjunction with vent compression. This is necessary when these technologies are paired with an OTEC facility and additional, higher grade thermal resources are not available. Reverse osmosis was evaluated with the consideration of using both warm and cold seawater as the feed water to the system. The four methods were then evaluated and compared to one another through a multi-criteria decision analysis.

From the MCDA it is determined that reverse osmosis is the preferred seawater desalination technology. More specifically, reverse osmosis of the warm surface seawater is the preferred method. The MED and MSF processes use far too much cold seawater and are too energy intensive, particularly for the 50 MGD production capacity. Using cold seawater with the reverse osmosis system might prove beneficial when used in conjunction with different OTEC designs. However, with this particular platform and power plant design, it does not seem practical. As in the case with the MED and MSF processes the cold seawater would be used in the SWRO process prior to passing through the OTEC system. This is due to the condenser design and the height of the platform. While cold-SWRO needs only a fraction of the cold water as the thermal processes, it still takes away from the electricity production. The combination of this, the efficiency loss and added capital and operating costs outweighs the filtration benefits of the cleaner, cold water.

There were five water distribution methods evaluated. These are: water bags, barges, tankers, pipeline and placing the water production plant on land and cabling power to it from the OTEC platform. For the purposes of this study, the delivery of the water is considered complete once it reaches the shore. Distribution of the water beyond that would be the same for any of the five methods. For the option of having the water plant on land and cabling power to it, there is no delivery system taken into account because the water is produced at what is considered to be the delivery point for all distribution methods. Capital costs and operating and maintenance costs were calculated for each of the additional four methods where applicable. Each method was also evaluated for distances from shore of 5 km, 25 km, and 50 km and production capacities of 1 MGD and 50 MGD.

The water bags might prove to be a viable means of water transportation in the future, but are not currently a commercial option. Attempts have been made to use this technology, but were abandoned due to problems with the bags structural reliability. There are a few companies addressing this issue in hopes of bringing the method back to the commercial realm.

Relative to the cost of the water production system, all methods of transporting water from the platform to shore were found to be expensive. The expense of the transport combined with the added cost of the platform for space and weight requirements of the water production plant are cost-

prohibitive. The best option was determined to be building the desalination plant on land and cabling the power to the land-based facility.

A life-cycle cost analysis was performed that covered 1 MGD production capacities and 50 MGD production capacities for both land-based and platform-based alternatives. The economics were shown to be best for the land-based system due to the high cost of platform additional platform space. None of the alternatives were shown to be cost competitive with bulk water supply rates under current US market conditions. This could change through advancements in platform technology, seawater desalination technology, decreased OTEC electricity prices or rising water costs. Based on global supply and demand trends, it seems likely that water costs will increase, perhaps dramatically, in the future.

Based on all of the information collected during this study and the analyses performed, it is recommended that seawater desalination in conjunction with the current design of the Lockheed Martin platform-based OTEC system be performed by a land-based SWRO system. Under certain conditions, a platform-based seawater desalination system might prove cost-effective. The determining factors as to whether water production in conjunction with OTEC can be cost effective are design specific as well as site specific. Evaluating every possible alternative for the combination of OTEC and water production is beyond the scope of this study.

LIST OF ABBREVIATIONS AND ACRONYMS

Acronym	Definition
°C	degrees Celsius
°F	degrees Fahrenheit
ABS	American Bureau of Shipping
CIP	clean in place
CWA	Clean Water Act
DO	dissolved oxygen
DWT	dead weight ton
ED	electrodialysis
EPA	Environmental Protection Agency
gpm	gallons per minute
IRR	internal rate of return
kgal	kilogallon
KUS$	thousands of United States dollars
kW	kilowatt
kWh	kilowatt hour
L	liter
m	meter
MCDA	multi-criteria decision analysis
MD	membrane distillation
MED	multiple effect distillation
mg	milligram
MGD	million gallons per day
MSF	multi-stage flash distillation
MTBF	mean time between failures
MTTR	mean time to repair
MVC	mechanical vapor compression
MW	megawatt
NF	nanofiltration
O&M	operations and maintenance
OTEC	ocean thermal energy conversion
PLC	programmable logic control
ppm	parts per million
ppt	parts per thousand
RE	Renewable energy
RBD	reliability block diagram
RO	reverse osmosis
ROI	return on investment
s	second
SS	stainless steel
SWRO	seawater reverse osmosis
TCF	temperature correction factor
TDS	Total dissolved solids
TFC	thin film composite
THMs	trihalomethanes
TRL	technology readiness level
TVC	thermal vapor compression
UNS	unified numbering system
US	United States
USGS	United States Geological Survey
VC	vent compression
VCD	vapor compression distillation
WHO	World Health Organization
µg	microgram

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Appendix A. Water Transport Costs

Table 11-1 Water Transport Costs Via Water Bags 50 MGD Capacity

Total Costs	50 MGD 50 km, 46 bags	50 MGD 50 km, 27 bags	50 MGD 25 km, 46 bags	50 MGD 25 km, 27 bags	50 MGD 25 km, 15 bags	50 MGD 5 km, 46 bags	50 MGD 5 km, 27 bags	50 MGD 5 km 15 bags	50 MGD 5 km 5 bags
Fuel	$395,623	$791,246	$197,812	$395,623	$789,901	$39,562	$79,125	$157,980	$775,098
Tug Crew Salaries	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000
Deck Crew Salaries	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000
Tug Insurance	$120,000	$120,000	$120,000	$120,000	$120,000	$120,000	$120,000	$120,000	$120,000
Tug Maintance	$450,000	$450,000	$450,000	$450,000	$450,000	$450,000	$450,000	$450,000	$450,000
Bag Repair	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000
SubTot	**$3,775,623**	**$4,171,246**	**$3,577,812**	**$3,775,623**	**$4,169,901**	**$3,419,562**	**$3,459,125**	**$3,537,980**	**$4,155,098**
Misc (1%)	$37,756	$41,712	$35,778	$37,756	$41,699	$34,196	$34,591	$35,380	$41,551
Annual O&M	***$3,813,379***	***$4,212,959***	***$3,613,590***	***$3,813,379***	***$4,211,600***	***$3,453,758***	***$3,493,716***	***$3,573,360***	***$4,196,649***
Tug Boat	$6,000,000	$6,000,000	$6,000,000	$6,000,000	$6,000,000	$6,000,000	$6,000,000	$6,000,000	$6,000,000
Connecting Pipes	$250,000	$250,000	$250,000	$250,000	$250,000	$250,000	$250,000	$250,000	$250,000
Water Bags	$18,400,000	$10,800,000	$18,400,000	$10,800,000	$6,000,000	$18,400,000	$10,800,000	$6,000,000	$2,000,000
TOTAL Capital	***$24,650,000***	***$17,050,000***	***$24,650,000***	***$17,050,000***	***$12,250,000***	***$24,650,000***	***$17,050,000***	***$12,250,000***	***$8,250,000***

Water transport costs via water bags for 50 MGD production rate – all alternatives of distance and number of bags considered.

Table 11-2 Water Transport Costs Via Water Bags 1 MGD Capacity

Total Costs	1 MGD 50 km 5 bags	1 MGD 50 km 3 bags	1 MGD 25 km 5 bags	1 MGD 25 km 3 bags	1 MGD 5 km 5 bags	1 MGD 5 km 3 bags
Fuel	$99,579	$199,157	$49,789	$99,579	$9,958	$19,916
Tug Crew Salaries	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000
Deck Crew Salaries	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000
Tug Insurance	$120,000	$120,000	$120,000	$120,000	$120,000	$120,000
Tug Maintance	$450,000	$450,000	$450,000	$450,000	$450,000	$450,000
Bag Repair	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000
SubTot	**$2,479,579**	**$2,579,157**	**$2,429,789**	**$2,479,579**	**$2,389,958**	**$2,399,916**
Misc= 1%	$24,796	$25,792	$24,298	$24,796	$23,900	$23,999
Annual O&M	***$2,504,374***	***$2,604,949***	***$2,454,087***	***$2,504,374***	***$2,413,857***	***$2,423,915***
Tug Boat	$6,000,000	$6,000,000	$6,000,000	$6,000,000	$6,000,000	$6,000,000
Connecting Pipes	$250,000	$250,000	$250,000	$250,000	$250,000	$250,000
Water Bags	$2,000,000	$1,200,000	$2,000,000	$1,200,000	$2,000,000	$1,200,000
TOTAL Capital	***$8,250,000***	***$7,450,000***	***$8,250,000***	***$7,450,000***	***$8,250,000***	***$7,450,000***

Water transport costs via water bags for 1 MGD production rate – all alternatives of distance and number of bags considered.

Table 11-3 Water Transport Costs Via Barge

Total Costs	50MGD 50 km (3 barges)	50MGD 25 km (2 barges)	50MGD 5 km (2 barges)	1MGD 50 km (2 barges)	1MGD 25 km (2 barges)	1MGD 5 km (2 barges)
Fuel	$16,770,600	$16,770,600	$16,770,600	$3,811,500	$3,811,500	$3,811,500
Tug Crew Salaries	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000
Deck Crew Salaries	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000
Tug Insturance	$600,000	$600,000	$600,000	$110,000	$110,000	$110,000
Barge Insurance	$4,800,000	$3,200,000	$3,200,000	$400,000	$400,000	$400,000
Tug Maintenance	$450,000	$450,000	$450,000	$450,000	$450,000	$450,000
Barge Maintenance	$900,000	$600,000	$600,000	$600,000	$600,000	$600,000
Pipeline Maintenance	$11,250	$11,250	$11,250	$11,250	$11,250	$11,250
Subtotal	**$21,081,850**	**$20,781,850**	**$20,781,850**	**$8,182,750**	**$8,182,750**	**$8,182,750**
Misc (1%)	$210,819	$207,819	$207,819	$81,828	$81,828	$81,828
Annual O&M	***$21,292,669***	***$20,989,669***	***$20,989,669***	***$8,264,578***	***$8,264,578***	***$8,264,578***
Tug	$30,000,000	$30,000,000	$30,000,000	$5,500,000	$5,500,000	$5,500,000
Barges	$240,000,000	$160,000,000	$160,000,000	$20,000,000	$20,000,000	$20,000,000
Mooring	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000
Connecting Pipes	$250,000	$250,000	$250,000	$250,000	$250,000	$250,000
Offshore Pipeline	$1,125,000	$1,125,000	$1,125,000	$1,125,000	$1,125,000	$1,125,000
TOTAL Capital	***$273,375,000***	***$193,375,000***	***$193,375,000***	***$28,875,000***	***$28,875,000***	***$28,875,000***

Water transport cost breakdown for barges – all alternatives evaluated

Table 11-4 Water Transport Costs Via Tanker

Total Costs	50MGD 50 km (3 tankers)	50MGD 25 km (3 tankers)	50MGD 5 km (2 tankers)	1MGD 50 km (2 tankers)	1MGD 25 km (2 tankers)	1MGD 5 km (2 tankers)
Fuel	$2,344,680	$1,172,340	$234,468	$46,894	$23,447	$4,689
Tanker Crew Salaries	$18,600,000	$18,600,000	$12,400,000	$12,400,000	$12,400,000	$12,400,000
Deck Crew Salaries	$800,000	$800,000	$800,000	$800,000	$800,000	$800,000
Tanker Insurance	$480,000	$480,000	$320,000	$320,000	$320,000	$320,000
Tanker Maintenance	$240,000	$240,000	$160,000	$160,000	$160,000	$160,000
Pipeline Maintenance	$11,250	$11,250	$11,250	$11,250	$11,250	$11,250
Subtotal	**$22,475,930**	**$21,303,590**	**$13,925,718**	**$13,738,144**	**$13,714,697**	**$13,695,939**
Misc (1%)	$224,759	$213,036	$139,257	$137,381	$137,147	$136,959
Annual O&M	***$22,700,689***	***$21,516,626***	***$14,064,975***	***$13,875,525***	***$13,851,844***	***$13,832,899***
Tankers	$24,000,000	$24,000,000	$16,000,000	$16,000,000	$16,000,000	$16,000,000
Mooring	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000
Connecting Pipes	$250,000	$250,000	$250,000	$250,000	$250,000	$250,000
Offshore Pipeline	$1,125,000	$1,125,000	$1,125,000	$1,125,000	$1,125,000	$1,125,000
TOTAL Capital	***$27,375,000***	***$27,375,000***	***$19,375,000***	***$19,375,000***	***$19,375,000***	***$19,375,000***

Water transport cost breakdown for tankers – all alternatives considered

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-40
Ammonia Table
OTEC-2010-001

17 September 2010

Prepared for:

Naval Facilities Engineering Command
Naval Facilities Engineering Service Center (NFESC)
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Prepared by:

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Distribution Statement A: Approved for public release; distribution is unlimited

Table A-4 Saturation Properties of Ammonia — SI Units (continued)

Temperature (°C)	Pressure (kPa)	Enthalpy (kJ/kg) Liquid	Enthalpy (kJ/kg) Vapor	Entropy (kJ/kg-K) Liquid	Entropy (kJ/kg-K) Vapor	Liq. Density (kg/m³)	Vapor Sp. Vol. (L/kg)
-32	108.26	54.675	1420.291	0.4362	6.0992	680.33	1056.717
0	429.38	200.000	1462.238	1.0000	5.6210	638.57	289.297
1	445.68	204.630	1463.303	1.0168	5.6080	637.20	279.247
2	462.46	209.265	1464.351	1.0336	5.5951	635.82	269.616
3	479.72	213.907	1465.382	1.0503	5.5822	634.44	260.384
4	497.48	218.554	1466.396	1.0670	5.5695	633.06	251.531
5	515.75	223.207	1467.393	1.0837	5.5568	631.66	243.039
6	534.53	227.867	1468.373	1.1003	5.5442	630.27	234.891
7	553.85	232.532	1469.335	1.1169	5.5317	628.87	227.071
8	573.70	237.204	1470.279	1.1334	5.5192	627.46	219.563
9	594.09	241.882	1471.206	1.1499	5.5069	626.05	212.352
10	615.05	246.566	1472.114	1.1664	5.4946	624.64	205.426
11	636.57	251.257	1473.004	1.1828	5.4824	623.22	198.770
12	658.66	255.954	1473.875	1.1992	5.4703	621.79	192.372
13	681.35	260.659	1474.728	1.2155	5.4583	620.36	186.221
14	704.63	265.369	1475.562	1.2318	5.4463	618.93	180.305
15	728.52	270.087	1476.376	1.2481	5.4344	617.49	174.614
16	753.03	274.812	1477.172	1.2643	5.4226	616.04	169.138
17	778.17	279.544	1477.948	1.2805	5.4108	614.59	163.867
18	803.95	284.283	1478.704	1.2967	5.3991	613.13	158.793
19	830.38	289.029	1479.441	1.3128	5.3874	611.67	153.906
20	857.48	293.783	1480.157	1.3289	5.3759	610.20	149.198
21	885.24	298.544	1480.853	1.3449	5.3643	608.72	144.662
22	913.69	303.313	1481.529	1.3610	5.3529	607.24	140.290
23	942.83	308.089	1482.184	1.3770	5.3415	605.76	136.076
24	972.68	312.874	1482.818	1.3929	5.3301	604.26	132.012
25	1003.24	317.667	1483.431	1.4089	5.3188	602.76	128.092
26	1034.53	322.468	1484.022	1.4248	5.3076	601.26	124.311
27	1066.56	327.277	1484.592	1.4406	5.2964	599.75	120.662
28	1099.34	332.095	1485.140	1.4565	5.2853	598.23	117.140
29	1132.88	336.921	1485.665	1.4723	5.2742	596.70	113.740
30	1167.20	341.757	1486.169	1.4881	5.2631	595.17	110.457
31	1202.30	346.601	1486.649	1.5038	5.2521	593.63	107.285
32	1238.19	351.455	1487.107	1.5196	5.2412	592.08	104.221
33	1274.89	356.318	1487.541	1.5353	5.2303	590.53	101.261
34	1312.42	361.190	1487.952	1.5509	5.2194	588.97	98.399
35	1350.77	366.073	1488.340	1.5666	5.2086	587.40	95.632
36	1389.97	370.965	1488.703	1.5822	5.1978	585.82	92.957
37	1430.02	375.867	1489.041	1.5979	5.1870	584.24	90.370
53	2197.10	455.866	1490.865	1.8451	5.0185	557.70	58.523
54	2253.58	460.977	1490.734	1.8604	5.0081	555.95	57.008
55	2311.13	466.103	1490.572	1.8758	4.9977	554.20	55.537
56	2369.78	471.244	1490.377	1.8911	4.9873	552.43	54.110
57	2429.54	476.401	1490.150	1.9064	4.9770	550.65	52.723

(Continued on next page)

Ammonia properties, published by the International Institute of Ammonia Refrigeration using REFPROP data

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.3-41
Initial Structure
OTEC-2010-001

17 September 2010

Prepared for:

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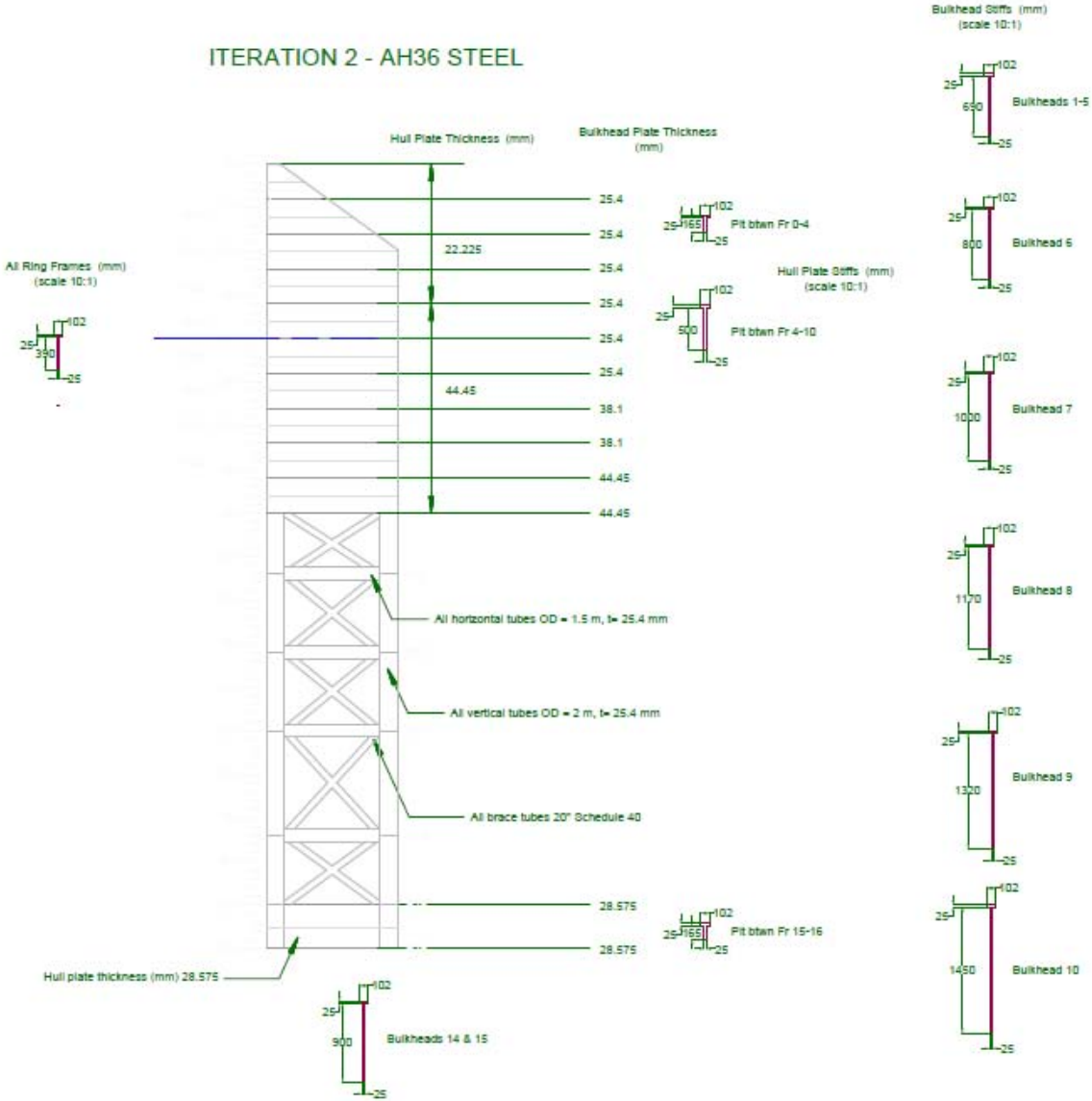
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APPENDIX 3.3.2.1.1-11

Remora Iteration 2—Definition of Structure

ITERATION 2 - AH36 STEEL



NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 3.5-1
Environmental Management
OTEC-2010-001

17 September 2010

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Distribution Statement A: Approved for public release; distribution is unlimited

Appendix 3.5

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3.5-1. Relevant Selected Laws, Executive Orders, Regulations and Directives1

- **Statutes**

The following items have been evaluated for applicability to the OTEC Pilot project and are indicative of the extent of laws and regulations affecting the EMS. This list will be evaluated for applicability and updates during the Planning and Permitting activities of the OTEC Pilot EMS. The list is not intended to be exhaustive.

ACT TO PREVENT POLLUTION FROM SHIPS, 33 U.S.C. 1901 *et seq.*

This law implements the International Convention on the Prevention of Pollution from Ships (MARPOL). It requires federal agencies to establish regulations to conform agency vessel operations to MARPOL requirements, to the extent reasonable and practicable. It mandates full compliance by U.S. government vessels with MARPOL garbage discharge requirements.

CLEAN AIR ACT (CAA), 42 U.S.C. 7401 *et seq.*

This is the major federal legislation addressing air pollution control. It establishes national ambient air quality standards (NAAQS) for common air pollutants ("criteria pollutants") and requires States to institute controls with established air quality control regions to achieve the NAAQS. It requires U.S. EPA to establish necessary air quality control where States fail to do so. Severity of controls increases as degree of nonattainment with NAAQS increases.

COASTAL ZONE MANAGEMENT ACT OF 1972 (CZMA), 16 U.S.C. 1451 *et seq.*

This law provides for States to develop and implement coastal zone management programs. Primarily a land use law, regulatory changes over the years has extended its role to enforceable policies of participating States with regards to coastal environmental resources. The law plays a significant role in water pollution abatement, particularly with regard to nonpoint source pollution. State coastal zone management programs frequently incorporate flood control, sediment control, grading control, and storm water runoff control statutes. Federal actions that impact the coastal zone must be consistent to the maximum extent practicable with the State program.

COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION, AND LIABILITY ACT OF 1980 (CERCLA), 42 U.S.C. 9601 *et seq.*

Also known as the Superfund Act, this law is the major federal legislation addressing cleanup of hazardous substance releases. (See also RCRA) It mandates reporting to National Response Center of hazardous substance releases.

EMERGENCY PLANNING AND COMMUNITY RIGHT-TO-KNOW ACT OF 1986 (EPCRA), 42 U.S.C. 11001 *et seq.*

This Act is also known as Title III of the Superfund Amendments and Reauthorization Act (SARA). EPCRA focuses on the hazards associated with toxic chemical releases. Most notably, specific sections of EPCRA require immediate notification of releases of oil and hazardous substances and CERCLA-defined hazardous substances to State and local emergency response planners. Requires State and local coordination in planning response

[1] Source: OPNAVINST 5090.1B, Appendix A. OPNAVINST 5090.1C is missing Appendix A.

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actions to chemical emergencies. Requires certain industries to submit information on chemical inventories and fugitive emissions.

ENDANGERED SPECIES ACT OF 1973 (ESA), 16 U.S.C. 1531 *et seq.*

This law provides for listing of endangered and threatened species of plants and animals, and designation of critical habitat for animal species. It establishes federal policy that federal agencies, in exercise of their authorities, shall seek to conserve endangered species. It prohibits federal agencies from taking any action that would adversely affect any endangered or threatened species, or critical habitat. It establishes a consultation process involving federal agencies generally and federal wildlife management agencies, to facilitate avoidance of agency action that would adversely affect species or habitat. It prohibits all persons subject to U.S. jurisdiction including federal agencies, from "taking" endangered species. Taking prohibition includes any harm or harassment, and applies within the U.S. and on the high seas. Violation of this law involves criminal penalties.

FEDERAL ANTI-DEFICIENCY ACT, 31 U.S.C. 1341 *et seq.*

This law provides that no Federal official or employee may obligate the government for the expenditure of funds before funds have been authorized and appropriated by Congress for that purpose. This law is considered when federal agencies negotiate with regulatory agencies to determine the nature and extent of applied mitigation.

FEDERAL WATER POLLUTION CONTROL ACT (CLEAN WATER ACT (CWA)), 33 U.S.C. 1251.

Generally known as the Clean Water Act, this is the major federal legislation addressing water pollution control. It establishes the National Pollution Discharge Elimination System (NPDES) permitting program, to control the discharge of pollutants from point sources into navigable waters. NPDES permits must incorporate industry-specific technology based effluent standards, as well as water quality based effluent standards.

HISTORIC SITES, BUILDINGS, AND ANTIQUITIES ACT, 16 U.S.C. 461 *et seq*.

This law requires Federal agencies to consider the existence and location of landmarks on the National Registry of Natural Landmarks to avoid undesirable impacts on such landmarks.

MARINE MAMMAL PROTECTION ACT OF 1972 (MMPA), 16 U.S.C. 1431 *et seq.*

This law prohibits the "taking" of marine mammals in the United States or on the high seas. "Taking" includes any harm or harassment.

MARINE PROTECTION, RESEARCH, AND SANCTUARIES ACT, 33 U.S.C. 1401

Implements for the United States the London Dumping Convention. It requires an EPA permit for transportation from the U.S., or from elsewhere in the world, of any "material" for the purpose of disposing of it in the ocean. It establishes the National Marine Sanctuary program, under which the National Oceanic and Atmospheric Administration (NOAA) designates and establishes regulations pertaining to national marine sanctuaries. NOAA regulations in some cases restrict discharges from vessels and aircraft.

MIGRATORY BIRD TREATY ACT (MBTA), 16 U.S.C. 703

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The MBTA prohibits taking or harming of migratory and certain other birds, their eggs, nests, or young without the appropriate permit.

MILITARY CONSTRUCTION AUTHORIZATION ACT OF 1975, 10 U.S.C. 2665

This law allows the proceeds from the sale of recyclable material to be credited to the installation to cover specified costs.

NATIONAL ENVIRONMENTAL POLICY ACT OF 1969 (NEPA), 42 U.S.C. 4321 *et seq.*

This keystone law mandates federal agency consideration and documentation of environmental impacts of proposed actions and legislation. It mandates preparation of comprehensive environmental impact statement for major federal actions that may significantly affect the quality of the human environment. After 40 years, this law has spawned global interest in environmental impact assessment and integrating multidisciplinary environmental involvement in decision making. The courts have established that federal agencies may make decisions based on their discretional authority, but only after taking a "hard look" at the potential environmental effects of their proposed actions.

NATIONAL HISTORIC PRESERVATION ACT (NHPA), 16 U.S.C. 470 *et seq.*

The NHPA requires Federal agencies to take account of the effect of any federally-assisted undertaking or licensing on any district, site, building, structure, or object that is included in or eligible for inclusion in the National Register of Historic Places. It provides for the nomination, identification (through listing on the National Register), and protection of historical and cultural properties of significance. Specific procedures are established for compliance, including initial review authority by the appropriate State Historical Protection Officer.

OCCUPATIONAL SAFETY AND HEALTH ACT OF 1970 (OSHA), 29 U.S.C. 651 *et seq.*

This law assures safe and healthful working conditions for men and women by authorizing enforcement of the standards developed under the Act; by assisting and encouraging the States in their efforts to assure safe and healthful conditions; by providing for research, information, education, and training in the field of occupational safety and health.

OIL POLLUTION ACT OF 1990 (OPA 90), 33 U.S.C. 2701 *et seq.*

This law mandates extensive planning for oil spills from tank vessels and onshore and offshore facilities. Establishes comprehensive elements of damage for oil spills, and imposes strict liability on those responsible for oil spills.

POLLUTION PREVENTION ACT OF 1990 (PPA), 42 U.S.C. 13101, *et seq.*

This law establishes the national policy that "pollution should be prevented or reduced at the source whenever feasible. Pollution that cannot be prevented should be recycled in an environmentally safe manner. Disposal or other release of pollutants into the environment should be employed only as a last resort and should be conducted in an environmentally sound manner."

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RESOURCE, CONSERVATION AND RECOVERY ACT OF 1976 (RCRA), 42 U.S.C. 6901 *et seq.*

The RCRA is the major federal legislation addressing hazardous waste management. RCRA amends the Solid Waste Disposal Act (SWDA). It establishes duties and responsibilities of hazardous waste generators, transporters, storers, treaters and disposers. It authorizes U.S. EPA to mandate cleanup of hazardous waste releases through "corrective action" orders. It regulates underground storage tanks, imposing structural integrity and management practice requirements.

TOXIC SUBSTANCES CONTROL ACT (TSCA), 15 U.S.C. 2601 *et seq.*

TSCA provides for the Federal regulation of the manufacture, use, distribution in commerce, and disposal of chemical substances that present a hazard to health or the environment. The major objective of TSCA is to characterize and understand the risks that a chemical poses to humans and the environment before it is introduced into commerce. The Act also contains specific requirements relative to Polychlorinated Biphenyls (PCBs), asbestos, and radon.

- **Selected Relevant Federal Regulations**

15 CFR 930, Federal Consistency with Approved Coastal Management Programs;

29 CFR 1910, Occupational Safety and Health Standards;

29 CFR 1910.120, Occupational Safety and Health Administration (OSHA) Regulations on Hazardous Waste and Emergency Response;

29 CFR 1910.1200, OSHA Hazard Communication Standard;

32 CFR 775, DON Procedures for Implementing the National Environmental Policy Act (NEPA);

36 CFR 800, National Historic Preservation Act (NHPA) Regulations for the Protection of Historic Properties;

40 CFR 50, Environmental Protection Agency Regulations on National Primary and Secondary Ambient Air Quality Standards;

40 CFR 53, EPA Regulations for Ambient Air Monitoring Reference and Equivalent Methods;

40 CFR 55, Outer Continental Shelf Air Regulations;

40 CFR 56, EPA Regulations on Regional Consistency Under the Clean Air Act;

40 CFR 58, EPA Ambient Air Quality Surveillance Regulations;

40 CFR 61, National Emissions Standards for Hazardous Air Pollutants;

40 CFR 68, Chemical Accident Prevention Provisions;

40 CFR 109, EPA Regulations on Criteria for State, Local, and Regional Oil Removal Contingency Plans;

40 CFR 110, EPA Regulations on Discharge of Oil;

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40 CFR 112, EPA Regulations on Oil Pollution Prevention;

40 CFR 113, EPA Regulations on Liability for Small Onshore Oil Storage Facilities;

40 CFR 116-117, EPA Regulations on Hazardous Substances;

40 CFR 122, EPA National Pollutant Discharge Elimination System Permit Regulations;

40 CFR 125, EPA Regulations on Criteria and Standards for the National Pollutant Discharge Elimination System;

40 CFR 129, EPA Toxic Pollutant Effluent Standards;

40 CFR 220-225, 227-229, Ocean Dumping Regulations and Criteria;

40 CFR 230, EPA Interim Regulations on Discharge of Dredged or Fill Material into Navigable Waters;

40 CFR 243, EPA Guidelines for Solid Waste Storage and Collection;

40 CFR 302, EPA Designation, Reportable Quantities and Notification Requirements for Hazardous Substances under CERCLA;

40 CFR 355, EPA Regulations for Emergency Planning and Notification under CERCLA;

40 CFR 414, EPA Effluent Guidelines and Standards for Organic Chemicals;

40 CFR 415, EPA Guidelines and Standards for Inorganic Chemicals;

40 CFR 417, EPA Effluent Guidelines and Standards for Soaps and Detergents;

40 CFR 433, EPA Effluent Guidelines and Standards for Metal Finishing;

40 CFR 760-761, EPA Regulations for Controlling PCBs;

40 CFR 1500-1508, Council on Environmental Quality Regulations on Implementing National Environmental Policy Act Procedures;

49 CFR 100-199, Department of Transportation Hazardous Materials Regulations;

50 CFR 10, Regulations Concerning Marine Mammals;

50 CFR 10.13, List of Migratory Birds;

50 CFR 17.11 and 17.12, Fish and Wildlife Service List of Endangered and Threatened Wildlife;

50 CFR 18, 216, 228, Regulations Concerning Marine Mammals;

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3.5-1. Preliminary Permitting Plan

A3.5-1.1. Background

The Ocean Thermal Energy Conversion (OTEC) Act of 1980 established NOAA as the licensing agency for OTEC plants, while granting the Secretary of Energy the authority to help expedite OTEC development for designated "OTEC Demonstration Projects." NOAA published OTEC regulations on July 31, 1981 (15 CFR 981). When it subsequently rescinded them on January 30, 1996 (61 FR 2970) because of inactivity, it left a permitting framework in place, but left the details to be worked out if and when the technology became financially feasible. Lockheed Martin (LM) is now proposing to develop the first OTEC Demonstration (or Pilot) Plant[2] to be followed shortly by the first Commercial OTEC Plant. The absence of regulations presents OTEC developers with considerable uncertainty for a project at either civilian or Navy sites. In addition to the OTEC Permit itself, this trail-blazing effort will require it to obtain a vast array of Federal, State and Local permits and approvals. These efforts may well be the primary schedule limitations of the current OTEC Program.

The technical objective of this task is to develop a specific technical approach for obtaining the approvals necessary to develop, fabricate, install, and operate an OTEC Pilot Plant facility.

While some approvals will be needed regardless of location, others are specific to the location ultimately selected for the facilities. Moreover, many of the specific activities (e.g., data collection, site-specific analyses, public outreach, etc.) required for permitting an OTEC facility are highly dependent on the location and specific system selected for the installation. In particular, a thorough environmental sampling at the selected site and analysis of the collected samples are required to characterize adequately the biological and oceanographic parameters of the selected Pilot Plant site.

During the initial phases of the project, the LM Team selected a site off the southwestern coast of the Island of Oʻahu, Hawaiʻi. The primary objective for this Preliminary Permitting Plan to detail the key environmental assessment work and permitting information inputs needed to obtain all major permits and environmental documentation required in order to develop a Pilot Plant at that location. A secondary purpose was to outline the likely permitting and environmental assessment steps that will be required for a commercial-scale plant at approximately the same site.

Completion of the Preliminary Permitting Plan included the following steps:

1. Confer with appropriate Federal and State of Hawaiʻi agency representatives to confirm the permits likely to be required and obtain guidance related to the environmental data that would be needed for applications.
2. Complete a first-order definition of the key environmental parameters that must be characterized, including specific variables to measure and duration of collected data.
3. Complete a list of permits and other approvals required, including specification of the information requirements and a preliminary schedule for their acquisition.
4. Integrate the results from the above into a draft and then final Preliminary Permitting Plan.

A3.5-1.2. Organization

The balance of this document is divided into the following sections:

[2] As used in this report, the terms "Demonstration Project" and "Pilot Plant" are synonymous, with the former showing the clear relationship of the first phase of the effort to the exceptions provided for in the OTEC law. However, because it better emphasizes the parallel between the "Pilot Projects" that are provided for in existing Federal regulations governing hydrokinetic energy projects (see 16 U.S.C. § 796), the term Pilot Plant is used most frequently.

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- Section A3.5-2.3 discusses the history and primary conclusions obtained to date from consultations with the appropriate Federal and State agency representatives;
- Section A3.5-2.4 describes the major permits and other approvals that are anticipated for the Pilot and commercial plants; and
- Section A3.5-2.5 presents an anticipated schedule for completion of these tasks.

A3.5-1.3. Agency Consultation

Agencies Contacted

LM team members have been meeting with representatives of Federal and State of Hawai'i regulatory agencies since 2008. These meetings are documented in Table 1 and Table 2. During these meetings the team briefed the government workers on the general aspects of the LM OTEC program and sought guidance related to the permitting steps that should be anticipated and the procedural and environmental issues that will have to be resolved. The key points related specifically to permit requirements are outlined below.

Table 1 Meeting History

Meeting #	Organization	Type*	Date	Time
1	State Coastal Zone Office	S	10/13/2008	9:30
2	Army Corps of Engineers	F	10/14/2008	13:30
3	Dept. of Health, Clean Water Branch	S	10/15/2008	13:30
4	Office of Coastal Zone Management	S	10/15/2008	15:30
5	National Marine Fisheries Service	F	12/2/2008	10:00
6	Office of Coastal & Conservation Lands	S	12/2/2008	13:00
7	Fish & Wildlife Service	F	12/3/2008	10:00
8	Bill Aila, Waianae Harbor master	N	2/18/2009	9:00
9	Life of the Land	N	2/18/2009	11:30
10	Navy Region Hawai'i	F	4/6/2009	13:00
11	Pacific Boats & Yachts LLC	N	4/7/2009	10:00
12	State Division of Aquatic Resources	S	4/8/2009	9:00
13	W. Pac. Reg. Fisheries Mgmt. Council	F	4/9/2009	14:00
14	U.S. Coast Guard	F	12/10/2009	10:00
	*F=Federal; S=State; L=Local; N= non-governmental			

Key Conclusions From Agency Meetings

- **Federal Permitting**

LM anticipates that the first OTEC plant will be a small-scale (5 to 10 MW) facility that the U.S. Department of Energy will designate as a "Demonstration Project". If this occurs, it will not require a

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NOAA license. Because the plant site will be outside of State jurisdiction, it will not require a Department of the Army Section 404[3] permit or the associated Water Quality Certification. A

Table 2 Non-Project Staff Meeting Participants

Meeting #	Participant	Affiliation	email
1	John Nakagawa	State Coastal Zone Office, DBEDT	jnakagaw@dbedt.hawaii.gov
2	Farley Watanabe	Corps of Engineers	Farley.K.Watanabe@poh01.usace.army.mil
2	Derek Chow	Corps of Engineers	Derek.J.Chow@usace.army.mil
3	Joanna Seto	Dept. Health, Clean Water Branch	joanna.seto@doh.hawaii.gov
3	Terence Teruya	Dept. Health, Clean Water Branch	terence.teruya@doh.hawaii.gov
3	Mark Tomomitsu	Dept. Health, Clean Water Branch	mark.tomomitsu@doh.hawaii.gov
3	Ed Chen	Dept. Health, Clean Water Branch	edward.chen@doh.hawaii.gov
4	Josh Strickler	Energy Coordinator, DBEDT	Joshua.b.strickler@dbedt.hawaii.gov
5	Alan Everson	NMFS	Alan.Everson@noaa.gov
5	Don Hubner	NMFS	Donald.Hubner@noaa.gov
5	Danielle Jayewardene	NMFS	
6	Sam Lemmo	DLNR OCCl	Sam.J.Lemmo@hawaii.gov
7	Dwayne Minton	US Fish & Wildlife Service	Dwayne_Minton@fws.gov
7	Patrice Ashfield	US Fish & Wildlife Service	Patrice_Ashfield@fws.gov
7	Wendy Wiltse	EPA Region IX Representative	wiltse.wendy@epa.gov
8	Bill Aila	Waianae Harbormaster	Waianae.harbor@hawaii.gov
9	Henry Curtis	Life of the Land	henry.lifeoftheland@gmail.com
9	Kat Brady	Life of the Land	katbrady@hotmail.com
10	C.B. Shaw	Navy Pearl Harbor	claude.shaw@navy.mil
11	Rick Gaffney	President, Pacific Boat & Yachts	rick.pacific@gmail.com
12	Jeff Walters	DLNR DAR	Jeffrey.S.Walters@hawaii.gov
13	Eric Kingma	WPRFMC, NOAA	Eric.Kingma@noaa.gov
13	Kelly Finkl	WPRFMC, NOAA	
13	Josh Demello	WPRFMC, NOAA	
13	Charles Ka`ai`ai	WPRFMC, NOAA	
14	Lt. Doug Miller	U.S. Coast Guard	douglas.j.miller@uscg.mil

Section 10[4] Dept. of the Army permit will be required for the power cable installation that will occur within State jurisdiction. The project will require either a National Environmental Policy Act

[3] Clean Water Act, §404
[4] Rivers and Harbors Act, §10

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(NEPA) Environmental Assessment (EA) or Environmental Impact Statement (EIS). An NPDES discharge permit will be required from the EPA Region IX.

Key issues both for NEPA compliance (formal consultation with NMFS) and NPDES permit acquisition will be related to the potential entrainment of biota in the OTEC water intakes and impingement of biota on intake screens. EPA would apply the same limits related to water intake velocity and discharge plume pollutants that it currently uses for power plant cooling water, unless the applicant can demonstrate clearly that alternate means would have less or similar impacts. Potential effects on marine mammals will be of particular concern to NMFS.

- **State and Local Permitting**

A Conservation District Use Permit will be required from the State (OCCL) for the power cable installation. This triggers the State environmental law (Hawai‘i Revised Statutes, Chapter 343) and the requirement for a State EA or EIS. Because the platform is part of the same undertaking, the State-level (Chapter 343) documentation must cover the entire system, not just the portion that is within Sate waters. State CZM certification from the Hawai‘i Coastal Zone Management Program and land lease from the State of Hawai‘i Board of Land and Natural Resource for the use of the portion of the cable route that is within three miles of the certified shoreline would also be required.

If the cable landing is on Federally controlled land, as it would be for the Pearl Harbor option (Figure 1.1), no local permits would be required. If the landing is on land controlled by the State or County, a Special Management Area permit would be required from the County, as well as an easement from the landowner(s) across whose property it passes.

A3.5-1.4. Permits and Other Approvals

Table 4.1 presents the major land use permits that could be required for an OTEC plant installed offshore within the Hawaiian Islands. NEPA and Chapter 343 requirements are outlined in Section 3. The other approvals described in the table are summarized below.

Federal Permits

- **OTEC License**

OTECA (42USC9101-9168) charges NOAA to “establish a legal regime which will permit and encourage the development of ocean thermal energy conversion as a commercial energy technology;” §9101(a)(4). The law requires NOAA to license commercial OTEC operations (§9111(a)) and authorizes DOE to designate an OTEC project as a “demonstration project” and further to waive any requirements of the Act that it deems appropriate (§9126(b)).

NOAA promulgated regulations to implement OTECA in 1986, but then rescinded them in 1996 after no license applications were received. Currently, in consultation with DOE and other Federal agencies, NOAA is beginning to work on a new set of regulations that will implement the law in the future. As noted above, representatives of NOAA have stated that DOE believes it is appropriate to designate the first OTEC plant to be proposed as a demonstration project.

- **National Pollutant Discharge Elimination System (NPDES) Permit**

This approval is needed in order to discharge water from the facility. For any Hawai‘i-based OTEC plant, this permit must be obtained from EPA Region IX. The key evaluation criteria for permitting are the CWA §403 criteria (40CFR125.122), listed as follows:

1) The quantities, composition and potential for bioaccumulation or persistence of the pollutants to be discharged.

2) The potential transport of such pollutants by biological, physical or chemical processes.

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3) The composition and vulnerability of the biological communities which may be exposed to such pollutants, including the presence of unique species or communities of species, the presence of species identified as endangered or threatened pursuant to the Endangered Species Act, or the presence of those species critical to the structure or function of the ecosystem, such as those important for the food chain.

4) The importance of the receiving water area to the surrounding biological community, including the presence of spawning sites, nursery/forage areas, migratory pathways, or areas necessary for other functions or critical stages in the life cycle of an organism.

5) The existence of special aquatic sites including, but not limited to marine sanctuaries and refuges, parks, national and historic monuments, national seashores, wilderness areas and coral reefs.

6) The potential impacts on human health through direct and indirect pathways.

7) Existing or potential recreational and commercial fishing, including finfishing and shellfishing.

8) Any applicable requirements of an approved Coastal Zone Management plan.

9) Such other factors relating to the effects of the discharge as may be appropriate.

10) Marine water quality criteria developed pursuant to section 304(a)(1).

In addition, NPDES permitting requires compliance with the Clean Water Act §316, which regulates the design and operation of cooling water intakes for power plants of all kinds.

- **Department of the Army Permit**

The Army Corps of Engineers issues two kinds of Department of the Army (DA) permits, one kind authorized under the Clean Water Act, §404 (33USC1344) and another under Section 10 of the Rivers and Harbors Act (33USC403). The former is required for projects that discharge materials (e.g. dredge spoils) in waters within State jurisdiction; the latter is required for the emplacement of any object that might obstruct navigation in these waters. The 404 permit requires an associated Water Quality Certification (33USC1341), issued in Hawai‘i by the State Department of Health. The Section 10 permit is generally much simpler to obtain and requires only that the emplaced object (in this case the cable to shore) not obstruct navigation. If the cable is emplaced simply on the seafloor and the landing is made using horizontal drilling technology rather than trenching, the COE Honolulu District will probably require only the Section 10 permit for an OTEC plant.

- **Coastal Zone Management Certification**

In Hawai‘i this required certification for the project is obtained from the State Office of Planning. It requires completion of an extensive form detailing potential impacts to the coastal zone. For an OTEC project, this certification will be sought in conjunction with the environmental impact assessment (probably the Draft EA or the Draft EIS), since the topics listed in the certification form are all examined in the impact analysis.

- **Endangered Species Act (ESA), Section 7 Consultation**

ESA Section 7 consultation is a detailed process used by FWS and NMFS to determine whether an action proposed by another Federal agency jeopardizes the health of endangered or threatened species (Figure 4.1). FWS has review authority over predicted impacts to ESA-listed bird species that might occur near the project site (e.g. the Newell's Shearwater, the Hawaiian Petrel); NMFS is responsible for listed fish and marine mammal species (e.g. green turtles, monk seals).

This consultation takes place concurrently with the drafting of the environmental impact assessment and is made public in that document. It will be an important part of the assessment process and will include specialist studies of the endangered species expected in the area. Results of these surveys and

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analyses can lead to requirements to modify the OTEC system design or constrain its operation in order to mitigate any potential impacts on listed species. Hence, it is typically done as early in the process as is practical.

State Permits

- **Conservation District Use Permit (CDUP)**

A CDUP is required for all activities that take place within three miles of the State-certified shoreline. This permit application is processed by the Office of Conservation and Coastal Lands (OCCL) within the State of Hawai'i Department of Land and Natural Resources. The Board of Land and Natural Resources issues the permit itself. A State EA/FONSI or EIS must be completed before OCCL will evaluate the application.[5, 6] The Department has the option of whether or not to hold a formal public hearing to seek public input on the application; for a project such as OTEC it is likely to exercise this option. Once it has completed its review of the application, supporting environmental documentation, and public comments, the agency staff formulates recommendations to the Board as to whether, and with what conditions, a permit should be issue. OCCL presents its recommendations to the State Board of Land and Natural Resources (BLNR). The Board takes public testimony on the application and votes to deny, issue, or issue with conditions. The BLNR decision on the matter can be contested by any party at this hearing, and the matter will then be decided at a later date by an Administrative judge in a subsequent hearing. This permit will not be required if the applicant is the U.S. Navy.

- **Submerged Land Lease**

The project applicant must negotiate a land lease with the State for installation of the seafloor cable within State jurisdiction. The lease would be obtained from the State DLNR Land Office after the CDUP is obtained. This would not be required if the applicant is the U.S. Navy.

- **Onshore Easements or Land Lease**

The applicant must negotiate a land lease from the property owner along the landside cable route.

- **Shoreline Certification**

If the project requires an SMP, a survey of the landing site must determine the specific location of the shoreline, subject to the approval by the DLNR Land Board (which can take six months or more). This is necessary to determine the boundary between the CDUP jurisdiction (seaward of the boundary) and the SMP (landward of the boundary).

- **Special Management Area Use Permit (SMP)**

This permit is required from the County of Honolulu for projects that propose to install developments within the Special Management Area (SMA). The SMA boundary is defined for all Hawaiian coastlines and is generally 1,000 ft. or more from the shoreline. This permit also triggers the requirement for a State EA/FONSI or EIS. The permit might not be required for HDD installations and would not be required for cable landings on Federal land.

- **Shoreline Setback Variance**

This permit would be required from the County if it becomes necessary to install aboveground facilities within 40 feet of the shoreline. It is processed concurrently with the SMP.

[5] The Department will sometimes begin processing the CDUP with only a Draft EIS available.
[6] If the proposed project also requires a Special Management Area Permit (SMP) from the City & County of Honolulu, the SMP must be obtained before OCCL will consider the application.

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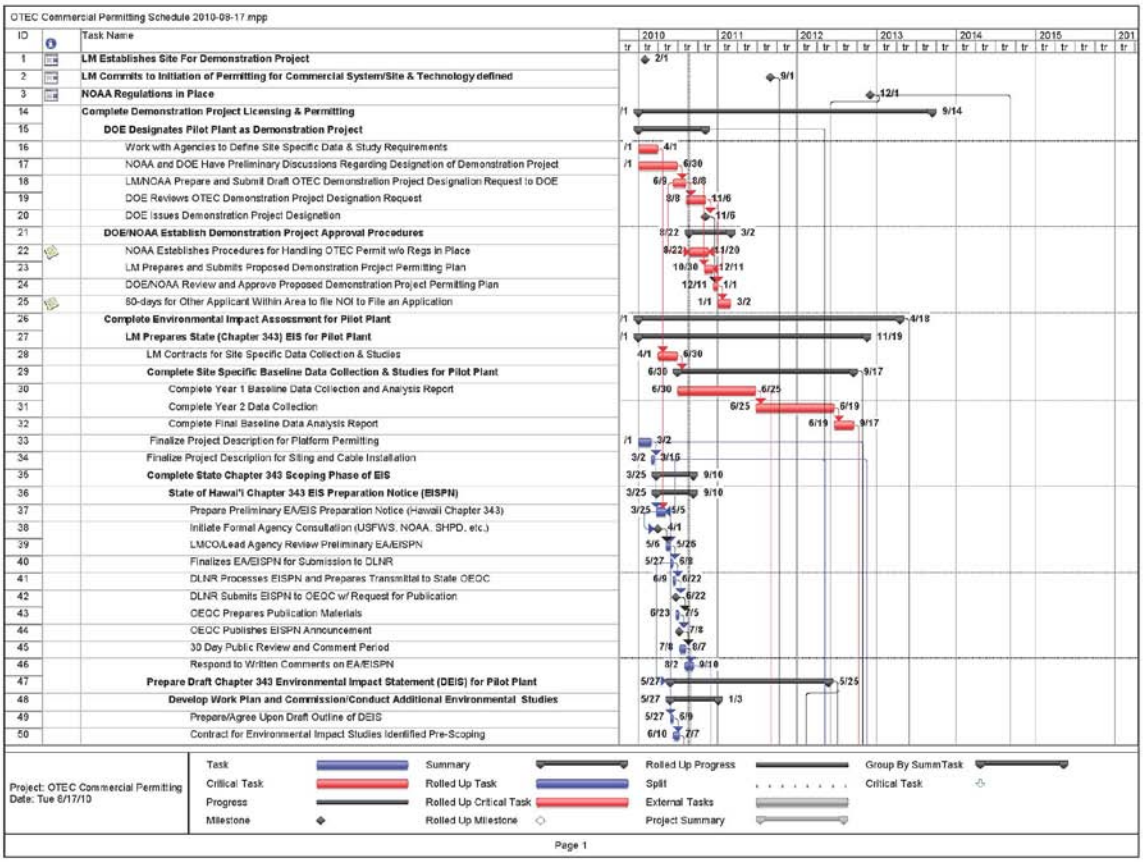
A3.5-1.5. Schedule

Figure 1 shows a preliminary schedule for obtaining the approvals required for the pilot plant and first commercial plant. This schedule assumes that DOE and NOAA would serve, respectively, as the lead agencies for the pilot and commercial plant NEPA compliance. Should the pilot plant be funded by the U.S. Navy, the Navy would be the lead agency for the pilot plant. Some of the additional key assumptions in this schedule are:

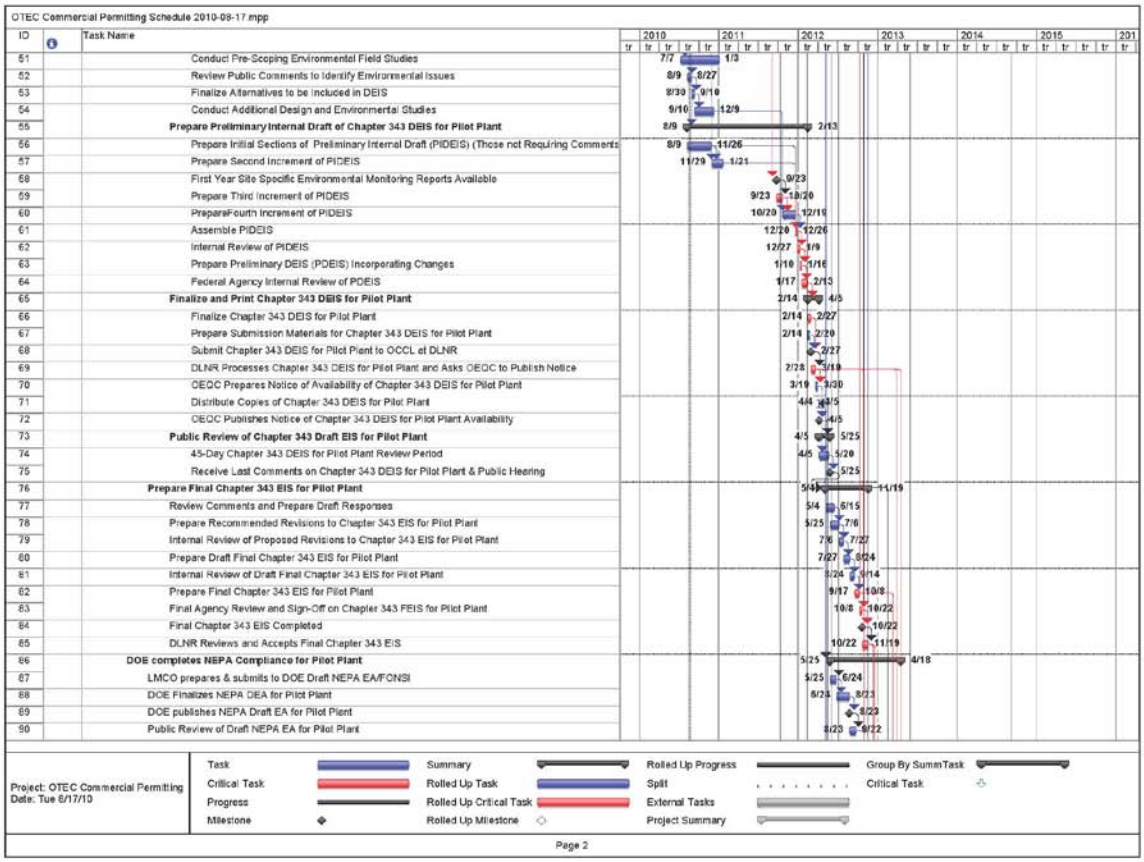
1. LM commits to initiate permitting for the commercial plant by the third quarter of 2011.
2. LM contracts for the first of two years of baseline data collection for the pilot plant in time for it to begin mid-year in 2010.
3. NOAA's regulations implementing OTECA are promulgated by the last quarter of 2012.
4. NEPA compliance for the pilot plant can be expedited to rely on the State EIS process for much of the analysis and can be completed by mid-2013.

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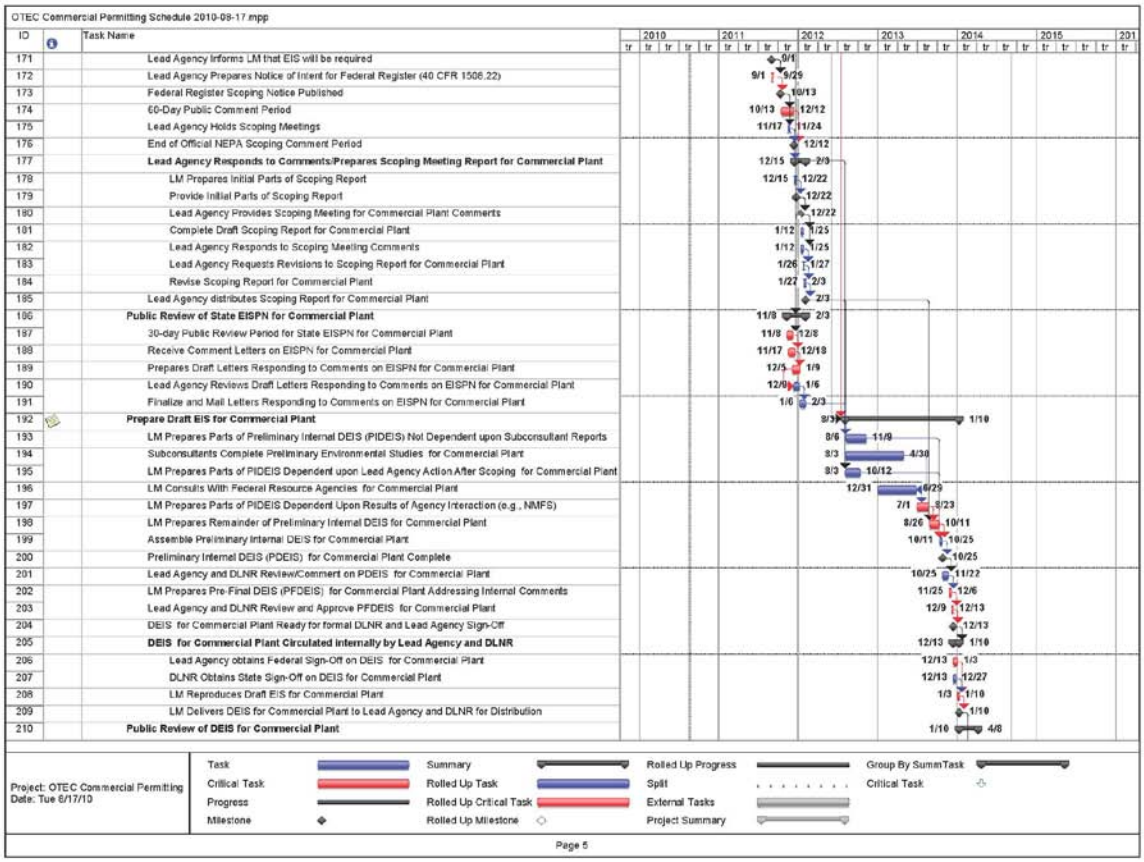
Figure 1 Preliminary Permitting Schedule



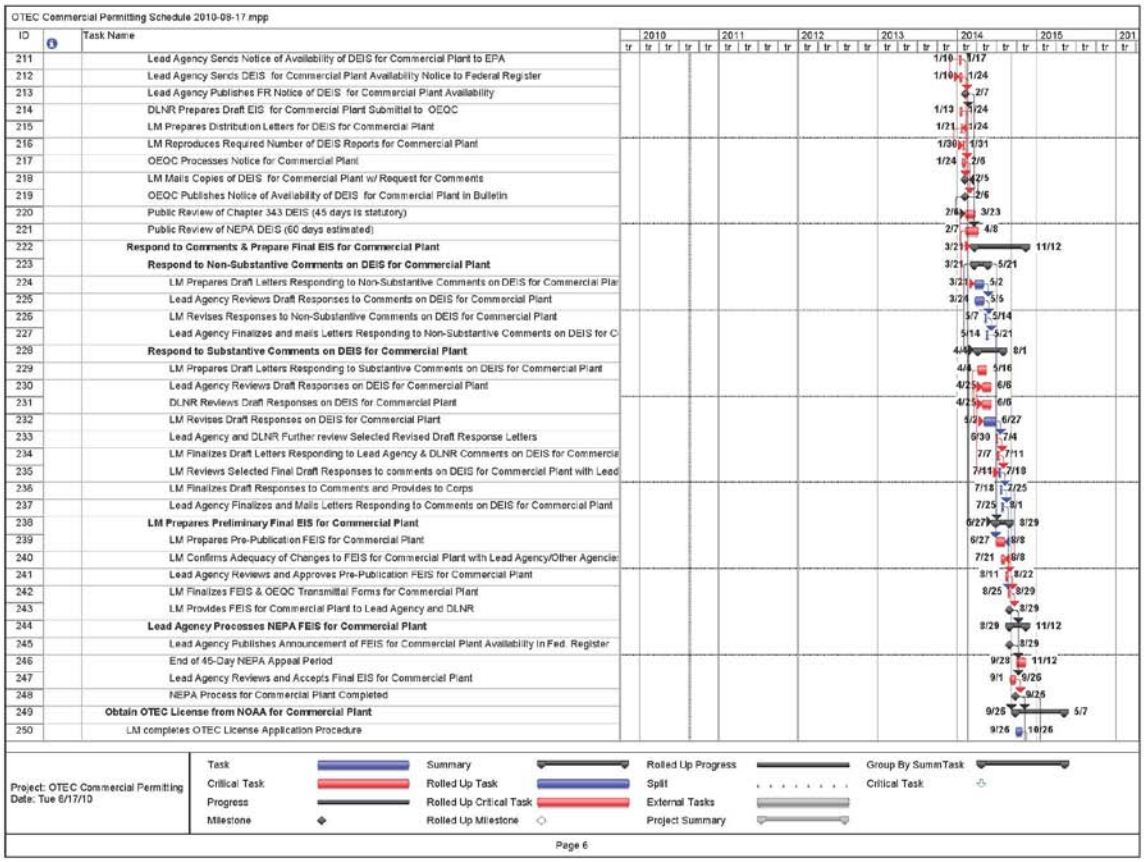
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OTEC Commercial Permitting Schedule 2010-09-17.mpp
ID
Task Name
2010
2011
2012
2013
2014
2015
51 Conduct Pre-Scoping Environmental Field Studies
52 Review Public Comments to Identify Environmental Issues
53 Finalize Alternatives to be Included in DEIS
54 Conduct Additional Design and Environmental Studies
55 Prepare Preliminary Internal Draft of Chapter 343 DEIS for Pilot Plant
56 Prepare Initial Sections of Preliminary Internal Draft (PIDEIS) (Those not Requiring Comments
57 Prepare Second Increment of PIDEIS
58 First Year Site Specific Environmental Monitoring Reports Available
59 Prepare Third Increment of PIDEIS
60 PrepareFourth Increment of PIDEIS
61 Assemble PIDEIS
62 Internal Review of PIDEIS
63 Prepare Preliminary DEIS (PDEIS) Incorporating Changes
64 Federal Agency Internal Review of PDEIS
65 Finalize and Print Chapter 343 DEIS for Pilot Plant
66 Finalize Chapter 343 DEIS for Pilot Plant
67 Prepare Submission Materials for Chapter 343 DEIS for Pilot Plant
68 Submit Chapter 343 DEIS for Pilot Plant to OCCL at DLNR
69 DLNR Processes Chapter 343 DEIS for Pilot Plant and Asks OEQC to Publish Notice
70 OEQC Prepares Notice of Availability of Chapter 343 DEIS for Pilot Plant
71 Distribute Copies of Chapter 343 DEIS for Pilot Plant
72 OEQC Publishes Notice of Chapter 343 DEIS for Pilot Plant Availability
73 Public Review of Chapter 343 Draft EIS for Pilot Plant
74 45-Day Chapter 343 DEIS for Pilot Plant Review Period
75 Receive Last Comments on Chapter 343 DEIS for Pilot Plant & Public Hearing
76 Prepare Final Chapter 343 EIS for Pilot Plant
77 Review Comments and Prepare Draft Responses
78 Prepare Recommended Revisions to Chapter 343 EIS for Pilot Plant
79 Internal Review of Proposed Revisions to Chapter 343 EIS for Pilot Plant
80 Prepare Draft Final Chapter 343 EIS for Pilot Plant
81 Internal Review of Draft Final Chapter 343 EIS for Pilot Plant
82 Prepare Final Chapter 343 EIS for Pilot Plant
83 Final Agency Review and Sign-Off on Chapter 343 FEIS for Pilot Plant
84 Final Chapter 343 EIS Completed
85 DLNR Reviews and Accepts Final Chapter 343 EIS
86 DOE completes NEPA Compliance for Pilot Plant
87 LMCO prepares & submits to DOE Draft NEPA EA/FONSI
88 DOE Finalizes NEPA DEA for Pilot Plant
89 DOE publishes NEPA Draft EA for Pilot Plant
90 Public Review of Draft NEPA EA for Pilot Plant
Project: OTEC Commercial Permitting
Date: Tue 6/17/10
Task
Critical Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Critical Task
Rolled Up Milestone
Rolled Up Progress
Split
External Tasks
Project Summary
Group By SummTask
Critical Task
Page 2

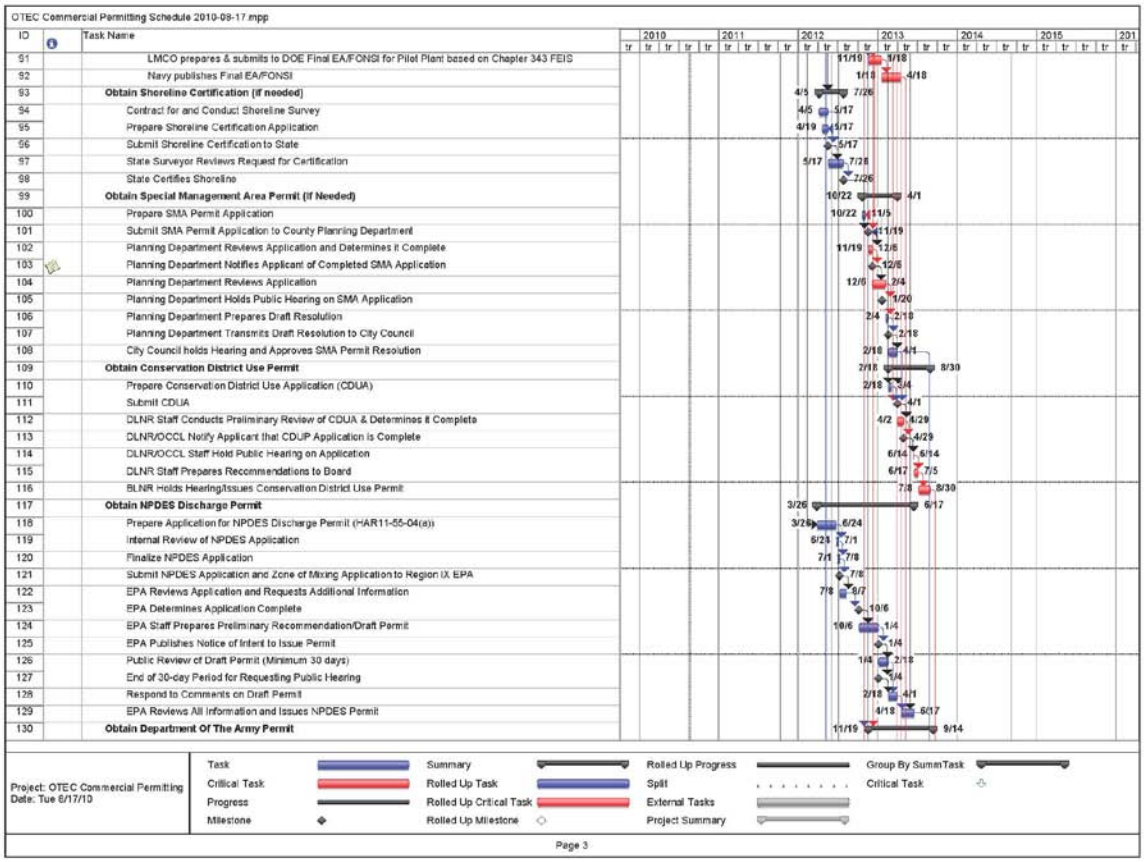
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OTEC Commercial Permitting Schedule 2010-09-17.mpp
ID
Task Name
2010
2011
2012
2013
2014
2015
171 Lead Agency Informs LM that EIS will be required
172 Lead Agency Prepares Notice of Intent for Federal Register (40 CFR 1508.22)
173 Federal Register Scoping Notice Published
174 60-Day Public Comment Period
175 Lead Agency Holds Scoping Meetings
176 End of Official NEPA Scoping Comment Period
177 Lead Agency Responds to Comments/Prepares Scoping Meeting Report for Commercial Plant
178 LM Prepares Initial Parts of Scoping Report
179 Provide Initial Parts of Scoping Report
180 Lead Agency Provides Scoping Meeting for Commercial Plant Comments
181 Complete Draft Scoping Report for Commercial Plant
182 Lead Agency Responds to Scoping Meeting Comments
183 Lead Agency Requests Revisions to Scoping Report for Commercial Plant
184 Revise Scoping Report for Commercial Plant
185 Lead Agency distributes Scoping Report for Commercial Plant
186 Public Review of State EISPN for Commercial Plant
187 30-day Public Review Period for State EISPN for Commercial Plant
188 Receive Comment Letters on EISPN for Commercial Plant
189 Prepares Draft Letters Responding to Comments on EISPN for Commercial Plant
190 Lead Agency Reviews Draft Letters Responding to Comments on EISPN for Commercial Plant
191 Finalize and Mail Letters Responding to Comments on EISPN for Commercial Plant
192 Prepare Draft EIS for Commercial Plant
193 LM Prepares Parts of Preliminary Internal DEIS (PIDEIS) Not Dependent upon Subconsultant Reports
194 Subconsultants Complete Preliminary Environmental Studies for Commercial Plant
195 LM Prepares Parts of PIDEIS Dependent upon Lead Agency Action After Scoping for Commercial Plant
196 LM Consults With Federal Resource Agencies for Commercial Plant
197 LM Prepares Parts of PIDEIS Dependent Upon Results of Agency Interaction (e.g., NMFS)
198 LM Prepares Remainder of Preliminary Internal DEIS for Commercial Plant
199 Assemble Preliminary Internal DEIS for Commercial Plant
200 Preliminary Internal DEIS (PDEIS) for Commercial Plant Complete
201 Lead Agency and DLNR Review/Comment on PDEIS for Commercial Plant
202 LM Prepares Pre-Final DEIS (PFDEIS) for Commercial Plant Addressing Internal Comments
203 Lead Agency and DLNR Review and Approve PFDEIS for Commercial Plant
204 DEIS for Commercial Plant Ready for formal DLNR and Lead Agency Sign-Off
205 DEIS for Commercial Plant Circulated internally by Lead Agency and DLNR
206 Lead Agency obtains Federal Sign-Off on DEIS for Commercial Plant
207 DLNR Obtains State Sign-Off on DEIS for Commercial Plant
208 LM Reproduces Draft EIS for Commercial Plant
209 LM Delivers DEIS for Commercial Plant to Lead Agency and DLNR for Distribution
210 Public Review of DEIS for Commercial Plant
Project: OTEC Commercial Permitting
Date: Tue 6/17/10
Task
Critical Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Critical Task
Rolled Up Milestone
Rolled Up Progress
Split
External Tasks
Project Summary
Group By SummTask
Critical Task
Page 5

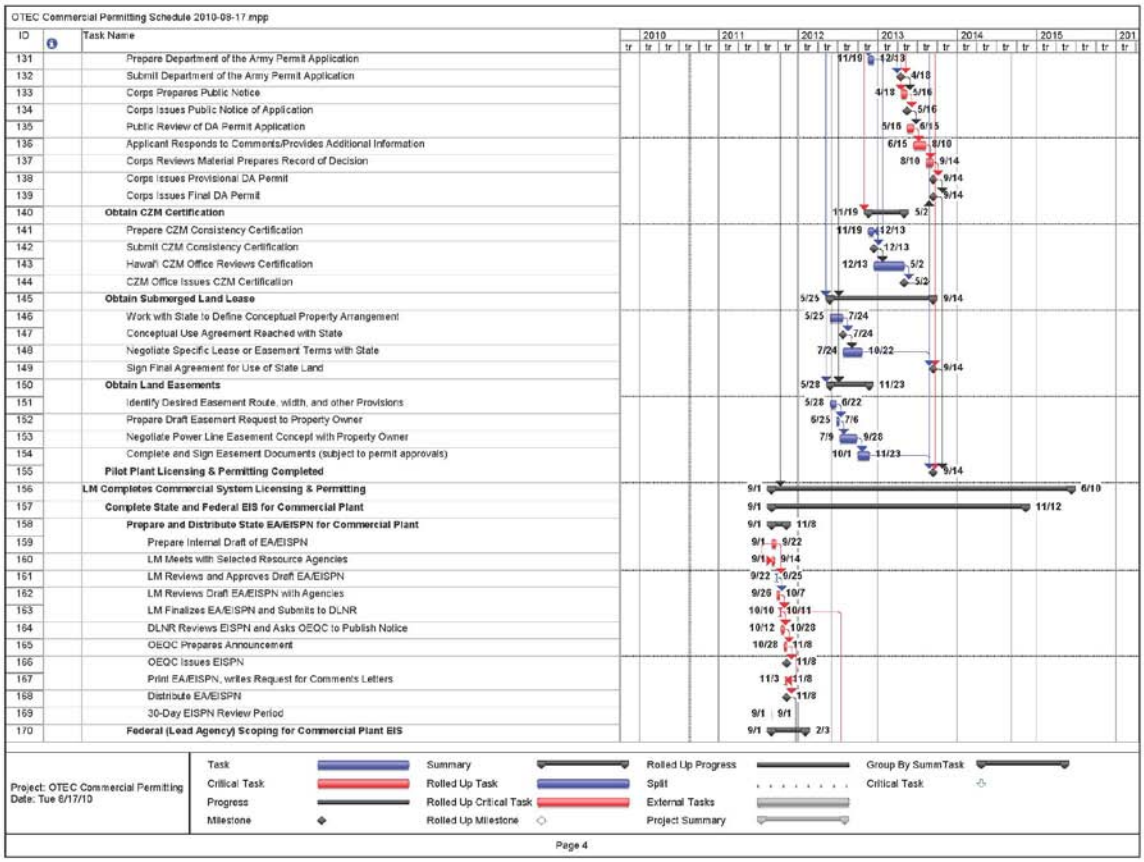
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OTEC Commercial Permitting Schedule 2010-09-17.mpp
ID
Task Name
2010
2011
2012
2013
2014
2015
211 Lead Agency Sends Notice of Availability of DEIS for Commercial Plant to EPA
212 Lead Agency Sends DEIS for Commercial Plant Availability Notice to Federal Register
213 Lead Agency Publishes FR Notice of DEIS for Commercial Plant Availability
214 DLNR Prepares Draft EIS for Commercial Plant Submittal to OEQC
215 LM Prepares Distribution Letters for DEIS for Commercial Plant
216 LM Reproduces Required Number of DEIS Reports for Commercial Plant
217 OEQC Processes Notice for Commercial Plant
218 LM Mails Copies of DEIS for Commercial Plant w/ Request for Comments
219 OEQC Publishes Notice of Availability of DEIS for Commercial Plant in Bulletin
220 Public Review of Chapter 343 DEIS (45 days is statutory)
221 Public Review of NEPA DEIS (60 days estimated)
222 Respond to Comments & Prepare Final EIS for Commercial Plant
223 Respond to Non-Substantive Comments on DEIS for Commercial Plant
224 LM Prepares Draft Letters Responding to Non-Substantive Comments on DEIS for Commercial Pla
225 Lead Agency Reviews Draft Responses to Comments on DEIS for Commercial Plant
226 LM Revises Responses to Non-Substantive Comments on DEIS for Commercial Plant
227 Lead Agency Finalizes and mails Letters Responding to Non-Substantive Comments on DEIS for C
228 Respond to Substantive Comments on DEIS for Commercial Plant
229 LM Prepares Draft Letters Responding to Substantive Comments on DEIS for Commercial Plant
230 Lead Agency Reviews Draft Responses on DEIS for Commercial Plant
231 DLNR Reviews Draft Responses on DEIS for Commercial Plant
232 LM Revises Draft Responses on DEIS for Commercial Plant
233 Lead Agency and DLNR Further review Selected Revised Draft Response Letters
234 LM Finalizes Draft Letters Responding to Lead Agency & DLNR Comments on DEIS for Commercia
235 LM Reviews Selected Final Draft Responses to comments on DEIS for Commercial Plant with Lead
236 LM Finalizes Draft Responses to Comments and Provides to Corps
237 Lead Agency Finalizes and Mails Letters Responding to Comments on DEIS for Commercial Plant
238 LM Prepares Preliminary Final EIS for Commercial Plant
239 LM Prepares Pre-Publication FEIS for Commercial Plant
240 LM Confirms Adequacy of Changes to FEIS for Commercial Plant with Lead Agency/Other Agencie
241 Lead Agency Reviews and Approves Pre-Publication FEIS for Commercial Plant
242 LM Finalizes FEIS & OEQC Transmittal Forms for Commercial Plant
243 LM Provides FEIS for Commercial Plant to Lead Agency and DLNR
244 Lead Agency Processes NEPA FEIS for Commercial Plant
245 Lead Agency Publishes Announcement of FEIS for Commercial Plant Availability in Fed. Register
246 End of 45-Day NEPA Appeal Period
247 Lead Agency Reviews and Accepts Final EIS for Commercial Plant
248 NEPA Process for Commercial Plant Completed
249 Obtain OTEC License from NOAA for Commercial Plant
250 LM completes OTEC License Application Procedure
Project: OTEC Commercial Permitting
Date: Tue 6/17/10
Task
Critical Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Critical Task
Rolled Up Milestone
Rolled Up Progress
Split
External Tasks
Project Summary
Group By SummTask
Critical Task
Page 6

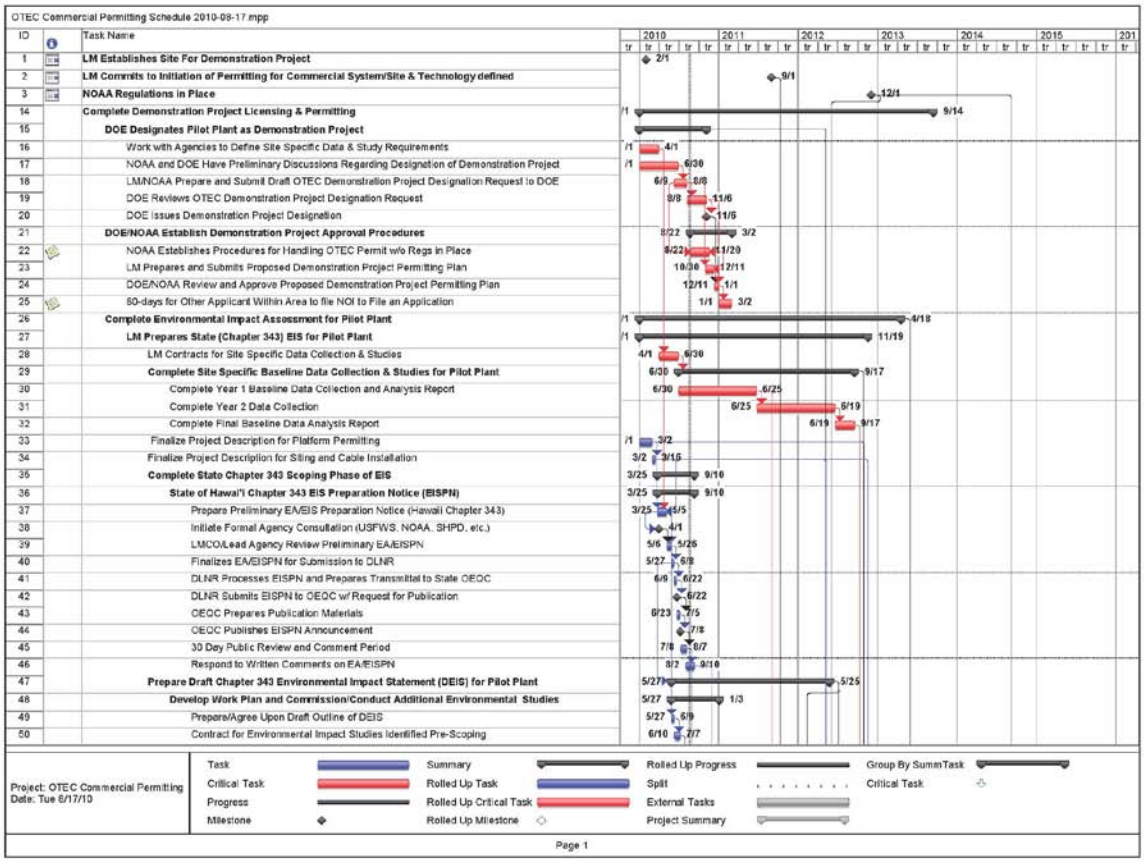
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OTEC Commercial Permitting Schedule 2010-09-17.mpp
ID
Task Name
2010
2011
2012
2013
2014
2015
91 LMCO prepares & submits to DOE Final EA/FONSI for Pilot Plant based on Chapter 343 FEIS
92 Navy publishes Final EA/FONSI
93 Obtain Shoreline Certification (if needed)
94 Contract for and Conduct Shoreline Survey
95 Prepare Shoreline Certification Application
96 Submit Shoreline Certification to State
97 State Surveyor Reviews Request for Certification
98 State Certifies Shoreline
99 Obtain Special Management Area Permit (if Needed)
100 Prepare SMA Permit Application
101 Submit SMA Permit Application to County Planning Department
102 Planning Department Reviews Application and Determines it Complete
103 Planning Department Notifies Applicant of Completed SMA Application
104 Planning Department Reviews Application
105 Planning Department Holds Public Hearing on SMA Application
106 Planning Department Prepares Draft Resolution
107 Planning Department Transmits Draft Resolution to City Council
108 City Council holds Hearing and Approves SMA Permit Resolution
109 Obtain Conservation District Use Permit
110 Prepare Conservation District Use Application (CDUA)
111 Submit CDUA
112 DLNR Staff Conducts Preliminary Review of CDUA & Determines it Complete
113 DLNR/OCCL Notify Applicant that CDUP Application is Complete
114 DLNR/OCCL Staff Hold Public Hearing on Application
115 DLNR Staff Prepares Recommendations to Board
116 BLNR Holds Hearing/Issues Conservation District Use Permit
117 Obtain NPDES Discharge Permit
118 Prepare Application for NPDES Discharge Permit (HAR11-55-04(a))
119 Internal Review of NPDES Application
120 Finalize NPDES Application
121 Submit NPDES Application and Zone of Mixing Application to Region IX EPA
122 EPA Reviews Application and Requests Additional Information
123 EPA Determines Application Complete
124 EPA Staff Prepares Preliminary Recommendation/Draft Permit
125 EPA Publishes Notice of Intent to Issue Permit
126 Public Review of Draft Permit (Minimum 30 days)
127 End of 30-day Period for Requesting Public Hearing
128 Respond to Comments on Draft Permit
129 EPA Reviews All Information and Issues NPDES Permit
130 Obtain Department Of The Army Permit
Project: OTEC Commercial Permitting
Date: Tue 6/17/10
Task
Critical Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Critical Task
Rolled Up Milestone
Rolled Up Progress
Split
External Tasks
Project Summary
Group By SummTask
Critical Task
Page 3

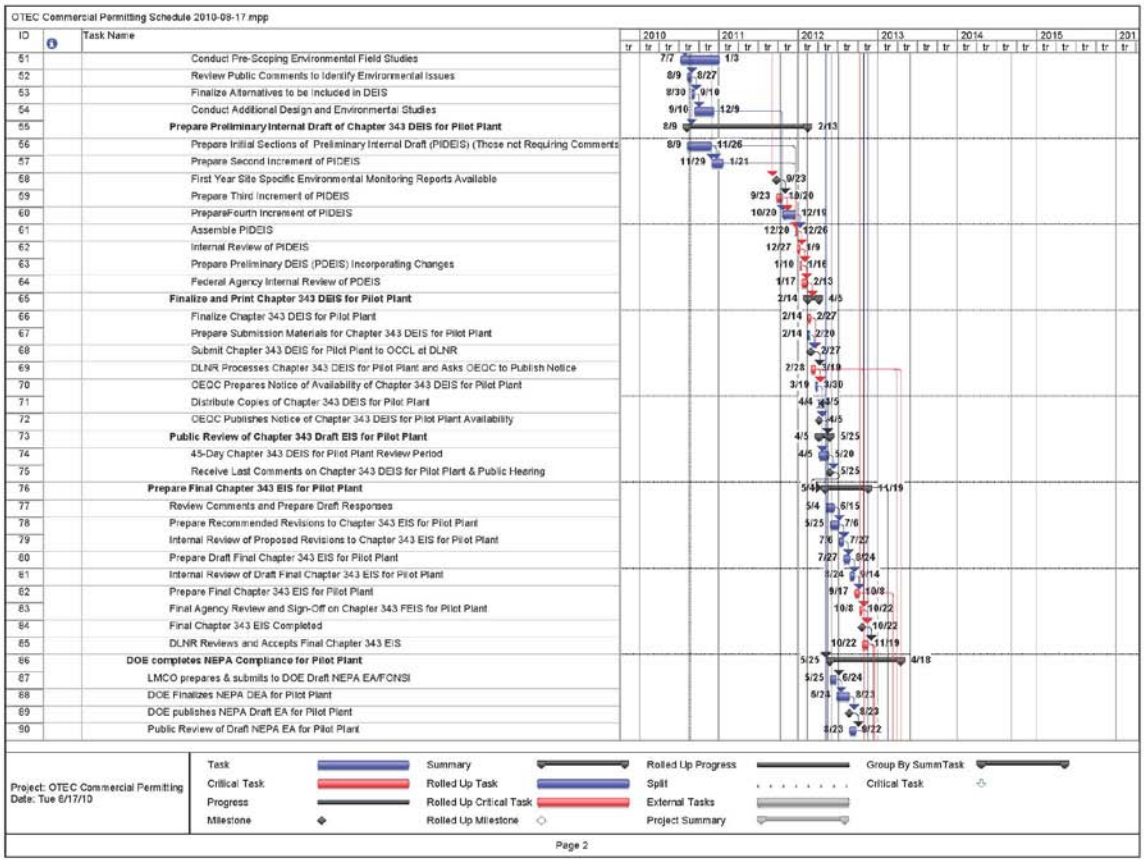
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OTEC Commercial Permitting Schedule 2010-09-17.mpp
ID
Task Name
2010
2011
2012
2013
2014
2015
131 Prepare Department of the Army Permit Application
132 Submit Department of the Army Permit Application
133 Corps Prepares Public Notice
134 Corps Issues Public Notice of Application
135 Public Review of DA Permit Application
136 Applicant Responds to Comments/Provides Additional Information
137 Corps Reviews Material Prepares Record of Decision
138 Corps Issues Provisional DA Permit
139 Corps Issues Final DA Permit
140 Obtain CZM Certification
141 Prepare CZM Consistency Certification
142 Submit CZM Consistency Certification
143 Hawai'i CZM Office Reviews Certification
144 CZM Office Issues CZM Certification
145 Obtain Submerged Land Lease
146 Work with State to Define Conceptual Property Arrangement
147 Conceptual Use Agreement Reached with State
148 Negotiate Specific Lease or Easement Terms with State
149 Sign Final Agreement for Use of State Land
150 Obtain Land Easements
151 Identify Desired Easement Route, width, and other Provisions
152 Prepare Draft Easement Request to Property Owner
153 Negotiate Power Line Easement Concept with Property Owner
154 Complete and Sign Easement Documents (subject to permit approvals)
155 Pilot Plant Licensing & Permitting Completed
156 LM Completes Commercial System Licensing & Permitting
157 Complete State and Federal EIS for Commercial Plant
158 Prepare and Distribute State EA/EISPN for Commercial Plant
159 Prepare Internal Draft of EA/EISPN
160 LM Meets with Selected Resource Agencies
161 LM Reviews and Approves Draft EA/EISPN
162 LM Reviews Draft EA/EISPN with Agencies
163 LM Finalizes EA/EISPN and Submits to DLNR
164 DLNR Reviews EISPN and Asks OEQC to Publish Notice
165 OEQC Prepares Announcement
166 OEQC Issues EISPN
167 Print EA/EISPN, writes Request for Comments Letters
168 Distribute EA/EISPN
169 30-Day EISPN Review Period
170 Federal (Lead Agency) Scoping for Commercial Plant EIS
Project: OTEC Commercial Permitting
Date: Tue 6/17/10
Task
Critical Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Critical Task
Rolled Up Milestone
Rolled Up Progress
Split
External Tasks
Project Summary
Group By SummTask
Critical Task
Page 4

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OTEC Commercial Permitting Schedule 2010-09-17.mpp
ID
Task Name
2010
2011
2012
2013
2014
2015
1 LM Establishes Site For Demonstration Project
2 LM Commits to Initiation of Permitting for Commercial System/Site & Technology defined
3 NOAA Regulations in Place
14 Complete Demonstration Project Licensing & Permitting
15 DOE Designates Pilot Plant as Demonstration Project
16 Work with Agencies to Define Site Specific Data & Study Requirements
17 NOAA and DOE Have Preliminary Discussions Regarding Designation of Demonstration Project
18 LM/NOAA Prepare and Submit Draft OTEC Demonstration Project Designation Request to DOE
19 DOE Reviews OTEC Demonstration Project Designation Request
20 DOE Issues Demonstration Project Designation
21 DOE/NOAA Establish Demonstration Project Approval Procedures
22 NOAA Establishes Procedures for Handling OTEC Permit w/o Regs in Place
23 LM Prepares and Submits Proposed Demonstration Project Permitting Plan
24 DOE/NOAA Review and Approve Proposed Demonstration Project Permitting Plan
25 60-days for Other Applicant Within Area to file NOI to File an Application
26 Complete Environmental Impact Assessment for Pilot Plant
27 LM Prepares State (Chapter 343) EIS for Pilot Plant
28 LM Contracts for Site Specific Data Collection & Studies
29 Complete Site Specific Baseline Data Collection & Studies for Pilot Plant
30 Complete Year 1 Baseline Data Collection and Analysis Report
31 Complete Year 2 Data Collection
32 Complete Final Baseline Data Analysis Report
33 Finalize Project Description for Platform Permitting
34 Finalize Project Description for Siting and Cable Installation
35 Complete State Chapter 343 Scoping Phase of EIS
36 State of Hawai'i Chapter 343 EIS Preparation Notice (EISPN)
37 Prepare Preliminary EA/EIS Preparation Notice (Hawaii Chapter 343)
38 Initiate Formal Agency Consultation (USFWS, NOAA, SHPD, etc.)
39 LMCO/Lead Agency Review Preliminary EA/EISPN
40 Finalizes EA/EISPN for Submission to DLNR
41 DLNR Processes EISPN and Prepares Transmittal to State OEQC
42 DLNR Submits EISPN to OEQC w/ Request for Publication
43 OEQC Prepares Publication Materials
44 OEQC Publishes EISPN Announcement
45 30 Day Public Review and Comment Period
46 Respond to Written Comments on EA/EISPN
47 Prepare Draft Chapter 343 Environmental Impact Statement (DEIS) for Pilot Plant
48 Develop Work Plan and Commission/Conduct Additional Environmental Studies
49 Prepare/Agree Upon Draft Outline of DEIS
50 Contract for Environmental Impact Studies Identified Pre-Scoping
Project: OTEC Commercial Permitting
Date: Tue 6/17/10
Task
Critical Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Critical Task
Rolled Up Milestone
Rolled Up Progress
Split
External Tasks
Project Summary
Group By SummTask
Critical Task
Page 1

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OTEC Commercial Permitting Schedule 2010-09-17.mpp
ID
Task Name
2010
2011
2012
2013
2014
2015
51 Conduct Pre-Scoping Environmental Field Studies
52 Review Public Comments to Identify Environmental Issues
53 Finalize Alternatives to be Included in DEIS
54 Conduct Additional Design and Environmental Studies
55 Prepare Preliminary Internal Draft of Chapter 343 DEIS for Pilot Plant
56 Prepare Initial Sections of Preliminary Internal Draft (PIDEIS) (Those not Requiring Comments
57 Prepare Second Increment of PIDEIS
58 First Year Site Specific Environmental Monitoring Reports Available
59 Prepare Third Increment of PIDEIS
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63 Prepare Preliminary DEIS (PDEIS) Incorporating Changes
64 Federal Agency Internal Review of PDEIS
65 Finalize and Print Chapter 343 DEIS for Pilot Plant
66 Finalize Chapter 343 DEIS for Pilot Plant
67 Prepare Submission Materials for Chapter 343 DEIS for Pilot Plant
68 Submit Chapter 343 DEIS for Pilot Plant to OCCL at DLNR
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88 DOE Finalizes NEPA DEA for Pilot Plant
89 DOE publishes NEPA Draft EA for Pilot Plant
90 Public Review of Draft NEPA EA for Pilot Plant
Project: OTEC Commercial Permitting
Date: Tue 6/17/10
Task
Critical Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Critical Task
Rolled Up Milestone
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Split
External Tasks
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3.5-2. Suggested Strategic Planning for a Navy Pearl Harbor OTEC Pilot project (NPH-OTEC)

A3.5-2.1. Project scope

Proposed Action

As envisioned, The Commanding Officer, Joint Base Pearl Harbor-Hickam (JBPHH) would propose to design, fabricate, install, operate and decommission a pilot Ocean Thermal Energy Conversion Pilot facility for Naval Station Pearl Harbor. This proposed action could be titled the Navy Pearl Harbor OTEC Pilot (NPH-OTEC) to be implemented by the Navy as the lead federal agency. This section provides information required by the Navy STEP-R process. (OPNAV 2007) The material below may be used by Navy to initiate the NEPA process, identify stakeholders and issues, conduct internal Navy scoping and prepare the Navy NEPA Notification. The objective of this baseline work is to finalize a strategic plan for Navy environmental planning compliance with Lockheed Martin support for a Lockheed Martin OTEC Pilot project facility.

In the long-term, the Navy objective is the promotion of OTEC technology to create new opportunities for purchase of power and water from a privately developed OTEC facility at cost-effective rates. Advancing OTEC technology to a commercially viable level is expected to involve several significant interim steps. The NPH-OTEC is a scaled megawatt pilot that can advance commercialization and promote future development of the OTEC technology. The OTEC technology is a potentially viable means to reduce dependence on fossil fuel at bases located in tropical areas, including Naval Support Facility Diego Garcia (NSFDG), as well as naval facilities in Hawai‘i and Guam.

The NPH-OTEC would be a small floating OTEC facility moored off the southwest side of O‘ahu, Hawai‘i. Electrical power would be cabled to a Pearl Harbor landing site and connected to the existing Pearl Harbor electrical system according to requirements of Navy and Hawai‘ian Electric Company (HECO). The NPH-OTEC would produce five megawatts net output (5 MWe). If successful, the NPH-OTEC system and subsystem technologies would be suitable for upgrading to commercial utility capacities ≥ 100 MWe. Consistent with other renewable energy technology development, this pilot project proposal is committed to:

- A limited operational duration of five years or less;
- Post-license environmental monitoring;
- Modification, shutdown, or removal in the event that monitoring reveals an unacceptable level of risk to the public or environmental harm; and
- Decommissioning and site restoration within five years of installation unless a new license is obtained.

Needs and purposes

Naval Station Pearl Harbor is a strategic military Naval Installation needing to continuously improve the percentage of energy procured from existing renewable and new renewable energy sources. Navy policy has been established is to help reduce dependence upon imported fossil fuels thus maintain readiness and sustainability. (SECNAV 2001; EO-13423 2007; DODINST-4170.11 2009) The ocean thermal energy resource is available close to Naval Station Pearl Harbor electrical loads, making this an excellent location for the development of ocean thermal energy conversion technology and the eventual use of OTEC-produced electricity.

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Providing support for alternative energy technological development is a current Navy policy promoting private alternative energy development and supply for the future. Demonstration of the engineering and environmental aspects of new OTEC technology would help further the development of renewable energy sources for the Navy in general and Navy Region Hawai'i in particular. In populated areas, the Navy typically procures electrical power for shore installations from private utilities. In remote areas and for emergency uses, however, Navy may construct and operate renewable energy technologies as a primary or secondary power source. In both cases, the availability of electrical energy from renewable energy sources that provide constant power output is advantageous.

The Navy Pearl Harbor OTEC Hawai'i Demonstration is in keeping with the National Defense Authorization Act of 2007, which requires 25% of electrical power from renewable sources by 2025. The project is also consistent with Navy's objectives to develop reliable power delivery to its facilities worldwide and to reduce dependence on fossil fuel while supporting its mission capabilities and readiness objectives. The Navy Pearl Harbor OTEC Demonstration is a congressionally funded project under the direction of the Navy's renewable energy research and development program.

A discussion of decision factors is not a strict requirement for the EA document level of NEPA compliance as defined at 40 CFR 1508.9, Environmental Assessment. However, a discussion relating the NEPA scope to the range of alternatives considered in the environmental analysis is usually needed for clarification. Also, the action purposes can be used as a tool to document selection of a preferred alternative.

The NPH-OTEC would provide the next logical step in OTEC development. A key to successful renewable energy technology development is the design, fabrication, installation, and operation of a pilot facility of sufficient scale to understand the risks and costs associated with building and operating commercial-scale facilities. To date, OTEC has only been demonstrated at a kilowatt scale. Commercial OTEC investors and builders must understand OTEC economics to sign long-term power purchase agreements and to sign fixed-price construction & installation contracts.

The ability to generate a mature OTEC system design requires decisions on major design requirements and operating location. These requirements establish the overall system performance and are then used to develop the requirements for lower-level systems under a process called "requirements flow-down." The objective of the NPH-OTEC is to provide at-sea demonstration of an integrated megawatt-scale OTEC system, thereby testing and validating the performance of major components and subsystems, as well as also validating the entire integrated OTEC system. A megawatt-scale NPH-OTEC will provide various stakeholders confidence that the technical challenges have been met sufficiently to enable a full-scale commercial OTEC Facility to be built and operated under a power purchase agreement. Furthermore, power delivered to Navy users ashore will enable an assessment of the quality of the power to be evaluated along with the best means of integrating it with the Navy's other electrical power sources.

The NPH-OTEC would be of sufficient scale to evaluate the following for a full-scale facility:

- Costs and schedules,
- Design performance,
- Environmental effects, and
- Operation & maintenance requirements.

The NEPA process is used to assess environmental impacts, influence decision making throughout technology development and to disclose these considerations to the public.

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Proposed Action

Ocean Thermal Energy Conversion is a sustainable energy production system that uses the temperature difference between warm surface water and deep cold ocean water to drive a Rankine cycle and generate electrical power. The surface ocean water is warmed by the sun and retains this thermal energy extremely well while the cold ocean water at depths of 700 meters and more is a heat sink. The thermal resource is available 24 hours a day enabling OTEC to generate electrical power on a continuous basis and is therefore classified as a base load power source unlike wind, wave, and solar photovoltaic that are intermittent depending on the availability of the source energy.(LMCO-MS2 2009)

Baseline Scope

- Location: Oahu, Hawaii, such that a power cable from the Pilot Plant can be brought ashore within the grounds of the Pearl Harbor Naval Base
- Size: 5 MW net electrical power output
- Design: Scaled version of future commercial plant to the maximum extent practical
- Purpose: Validation and Demonstration Activities; provide power ashore to validate power quality and establish grid interface protocol, perform ongoing product improvement of the OTEC critical components, provide confidence to proceed with commercial OTEC plant
- Lifetime: Provide electrical power to shore after Pilot Plant test phase (TBD years based on affordable post test phase upgrades)
- Status: R&D facility sponsored by the Navy and other project stakeholders,
- Operation: Lockheed Martin development team. (LMCO-MS2 2009)

Alternatives

The "heart" of the NEPA process is the comparison and consideration of alternatives. Reasonable alternatives are those that meet the action's purpose and need, and achieve its objectives. The Preferred Alternative is the option that is preferable to the decision-maker.

A final alternatives list will follow evaluation of action variables, tradeoff studies, and environmental scoping under NEPA. This report presents an initial listing of variable OTEC factors which could lead to alternatives (Tables 2 and 3). Variation in location, technology design or infrastructure can be used to create a set of reasonable alternatives that comply with NEPA regulations to meet the action need and achieve the action purposes. To define realistic alternatives, Table 3 and Table 4 list topics to be updated with improvements in systems engineering. Environmental team collaboration with Integrated Project Teams and tradeoff studies will help develop an accurate and realistic alternatives list.

Table 3 - NPH-OTEC options as a function of siting location

Variable	Possibilities (Alternatives)	Notes
Land-based Location	Only practical in a very few locations	Eliminated from consideration, since its design & development does not have general applicability

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Variable	Possibilities (Alternatives)	Notes
Platform Location	Non-Hawai‘i locations Kahe Pearl Harbor A Pearl Harbor B (analyzed) PMRF (not analyzed in detail - failure to meet purpose) MCBH (not analyzed in detail - failure to meet purpose)	Non-Hawai‘i sites eliminated early due to lack of suitable infrastructure availability for prototype development A clear rationale for the Pearl Harbor site selection, consistent with the proposed action and linked to action needs and purposes, will avoid risk of having to conduct detailed environmental site analysis at other sites Assume purposes, including practicability, derived from the SST site assessment and LMCO program input will support this decision. Sites PH(A) and PH(B) may be used as alternatives. Value of alternative in comparative analysis must be considered. Site alternatives A and B may not offer many environmental differences, thus appearing to be a construct.
Cable route & shore landing	Shortest Direct Route to Each Landing Point Routed to each landing point to avoid sensitive features Routed to Naval facility HDD or trenched shallow water burial	Assume also Navy has documentation or will document the selection of Pearl Harbor landing as not arbitrary or capricious. Site assessment is primary information source. Recommend augmenting the site assessment with geographic spatial planning for ecological and biological sensitivity, recreational fishing and military restriction. Trenched would require extensive additional permitting & environmental analysis
Interconnect Provisions	Tie with Existing Substation Construct new substation	Part of trade-off with landing site location

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Table 4 - NPH-OTEC options as a function of infrastructure or management variable and/or tradeoff analysis. These may be edited and others may have been inadvertently omitted. Access to discipline tradeoff studies will help define accurate and realistic alternatives.

Design Parameter	Possibilities (Alternatives)	Notes
OTEC facility type	Open Closed Hybrid	Closed system currently in design. Engineering rationale needed to demonstrate selection.
Scale of Project (Power Output)	5 MWe 10 MWe 100 MWe	Current design for single remora would produce 5 MWe Consideration is to design platform to permit installation of 2 remoras 100 MWe considered to be near low limit of commercial scale; would be very high risk without prior pilot scale
Cable Design	Select Sturdiest Capacity Lowest EMF or EMF not considered Cheapest	5 – 10 MWe currently conventional technology 100 MWe would require additional R&D w/ or w/o Expansion Capability Minimize cost by selecting smallest size and only 5-year life (durability)
Discharge Design	Discharge Depth Separate or Mixed Discharges	Depths under consideration for the discharge are between 50 & 150 m Current design calls for mixed discharges; could separate if necessary to mitigate environmental impacts;
Water production and delivery	Platform Land	See trade study 3.18.2 TDP
Platform Configuration	Semisubmersible platform Spar Vessel	Semisubmersible is the current design Use of Moth-balled Naval Vessel determined to be impractical Use of barge considered; need inputs from designers regarding decision to reject barge
Anchoring	Gravity PHA Drilled	Will depend on cost and seabed characteristics Placement must consider avoidance of hard-substrate habitats

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Design Parameter	Possibilities (Alternatives)	Notes
CWP construction method	Construct onsite Construct ashore	Onsite construction feasible for pilot scale but not for commercial scale
CWP size	4 m 10 m	Not a separate parameter. Need to describe basic relationship between size and power output
Operational Pattern	Continuous Discrete, limited	Continuous provides better opportunity to judge the readiness for commercial-scale operation and to observe longer-term environmental effects Provides better opportunity for power sales to cover substantial portion of costs Discrete (intermittent) operation allows for more operational experiments
Intake design	Variable screen sizes Variable intake areas No screen for cold water	Need to identify the specific screen sizes that will be tested (in lab and at-sea) Need to identify the intake velocities (and, therefore, intake areas) that are of interest Need to provide for w/ and w/o screen testing
Bio-fouling management	Continuous, low level Periodic, higher level	If chemical, need to identify substances that would be effective Need to establish release limits for ant-bio-fouling agents
Generator-heat exchange configuration (a.k.a. Remora)	Combined evaporator and condenser Separate evaporator and condenser	
Working fluid	Ammonia Alcohol Others?	
Security measures	Total exclusion zone around platform Regulated activities around platform No limits except for private property	Need to establish what is allowable under current regulations Need to assess threats (and their consequences) Need to identify enforcement resources/regime for each

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Design Parameter	Possibilities (Alternatives)	Notes
Acoustic signature	Variable by component	Sound isolation for individual components needed for supporting analysis.
Visual appearance	Color Height Silhouette	

No Action

The No Action alternative describes a scenario of not meeting the need as it would be with implementation of the preferred action alternative. Typically, the no action is used as a baseline comparison to determine effects of the action alternatives.

The no action alternative is the absence of the proposed action at the time of implementation. That is, the future state of the environment under a condition of not conducting the design, construction and operation of NPH-OTEC. In this instance it will mean not obtaining knowledge that is essential to commercializing OTEC and using it to reduce the Navy's existing dependence upon imported fossil fuels.

Other courses of action

The scope of this action is focused on decisions to be made by the Navy Region Hawai'i for the Commander, Joint Base Pearl Harbor. Navy documentation will need to be assembled to support the selection of Joint Base Pearl Harbor as the location for the power load for the OTEC Pilot facility. If such documentation is not available, the alternatives considered in analysis may be required to include a full environmental analysis of the other Hawaiian sites considered earlier.

There would be no other courses of action at this time and at this location that would fulfill the need and meet Navy's renewable energy technology development objectives as described in this report. Other renewable energy technologies do not include the capacity to produce energy constantly over time. Unlike wind and wave energy extraction, OTEC is dependent on the constant temperature differences between the ocean's surface and bottom; available constantly.

A3.5-2.2. Environmental Impact Analysis

Description of the Affected Environment would address the following concepts, as appropriate:

- Preliminary cause/effect/exposure diagnosis
- Available information in published literature
- Site selection process and results
- Planning for incomplete information
- Existing conditions studies commensurate with the importance of the impact
- Definition of the affected environment

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Impact Analysis

An analysis of changes from ambient conditions upon implementing the proposed action makes up the bulk of the environmental documentation. It concludes with a determination of the nature and level of effects caused by various components of the proposed action. In an EA, this also includes a determination of significance and supporting rationale.

Determining the meaningful environmental issues worthy of analysis is achieved by adjusting a standard set of environmental issues via analysis, agency coordination and public involvement. Through this process, important issues are emphasized and unimportant issues are eliminated from analysis. The NEPA scoping process is typically used as the baseline process to do this.

Baseline planning will diagnose environmental cause and effect relationships and present an issue-by-issue plan for impact analysis. A structured approach arranges impact topics as they will be discussed in the NEPA document. This report presents an issue list that will be updated with improvements in project design, environmental cause and effect analysis and environmental scoping.

NPH-OTEC Environmental Focus Issues:

1. Marine water quality
   1.1. Cold and warm water thermal discharges
   1.2. CO2/carbon budget
   1.3. Nutrient enrichment of surface waters
   1.4. HM/HW use and spill prevention for anticorrosion, antifouling and working fluids

2. Marine biology
   2.1. Impingement and entrainment of marine organisms
   2.2. Effect on listed ESA species
   2.3. Effect on Marine Mammals

3. Physical ecology
   3.1. Acoustic impacts
   3.2. Electromagnetic field impacts
   3.3. Anchor and sea floor impacts on benthic habitats
   3.4. Anchoring/storm reliability and risk
   3.5. Platform impacts on surface water and avian habitats
   3.6. Cable and shore

4. CZM consistency and HI State coastal land use

5. Impacts on Native Hawai‘ian and other cultural values

6. Visual impacts
   6.1. Ocean platform
   6.2. Shore power management facilities

7. Environmental justice

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Mitigating Environmental Impacts

As defined by NEPA regulations mitigation includes avoiding, reducing, rectifying and compensating for environmental impacts. Application of mitigation may occur at any time during project development. In the NEPA document, mitigation is treated variously depending upon how deeply environmental considerations have been integrated into project design. To illustrate, the cable route is partly defined by existing conditions, including wrecks and historic sites. The proposal for action would present a cable route that had already taken these sites into account. In this illustration, the mitigation of avoiding historic sites has already been taken into account by design. In the NEPA document the coordinated environmental and design effort may or may not be discussed depending on Agency discretion.

In practice, mitigation is often presented in the NEPA document as either optional (i.e., determined by the lead agency) or required (i.e., as determined by regulatory agency) above and beyond the proposed action. Mitigation could be of such a magnitude that it could be considered a distinct alternative in comparison to the proposed action.

The NPH-OTEC action scope incorporates environmental mitigation. During the Front End Engineering Design (FEED), environmental impact analysis has been applied to the design of primary NPH-OTEC systems. Lockheed Martin would identify the proposed action scope in baseline documentation and the proponent's environmental assessment. This scope would include the results of a matured FEED effort, including the results of an integrated Environmental Management System. Thus, the matured proposed action scope to be addressed in the NEPA documentation includes mitigation to reduce potential environmental effects to less than significant levels. The Navy would determine through the NEPA process whether or not the proposed action is suitable for a Finding of No Significant Impact.

The NEPA documentation for NPH-OTEC would address mitigation as determined by Navy action proponent policy. Minimally, this analysis would include any mitigation that supports a conclusion of insignificant environmental impact. However, as noted above, internal Navy review, agency review and public review of draft NEPA documentation may result in additional mitigation requirements. The integrated Environmental Management System would minimize adverse schedule or cost impacts of such additional mitigation.

Monitoring Environmental Impacts

At the time of decision, a monitoring and enforcement program must be considered where applicable for any mitigation. Agencies may provide for monitoring to assure that their decisions are carried out and should do so in important cases. A monitoring program will mature during environmental planning and permitting.

Monitoring is an element of the NPH-OTEC action scope that would achieve the purpose of this pilot project. Biological and water quality surveys would be conducted of the project area prior to the start of any work to establish baseline conditions. The parameters that are decided upon for this work would be those for which on-going monitoring will be conducted. This will also be linked to the environmental objectives established for the project.

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NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 4.1-1
OTEC Pilot Plant Master Test Plan Draft
OTEC-2010-001

17 September 2010

Prepared for:

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Master Test Plan (MTP)

for the

OTEC Pilot Plant

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Approval Page

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Master Test Plan (MTP)
for the OTEC Pilot Plant

Revision: Draft

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1 OVERVIEW

1.1 Introduction

This Master Test Plan (MTP) is the principle management tool of the Integration, Verification, and Validation (I,V&V) Program of the OTEC Pilot Plant. It is used, for the control, oversight, and provision of customer insight into Lockheed-Martin Corporation (LMCO) processes and procedures to be used in the OTEC Pilot Plant I,V&V Program. The OTEC collaboration repository contains the most up-to-date information, artifacts, and work products for the I,V&V Program.

1.1.1 Purpose

The purpose of the OTEC Pilot Plant MTP is to identify the tasks and activities needed to be performed so that all aspects of the system are adequately integrated and tested and that the system can be successfully implemented. This MTP documents the scope, content, methodology, sequence, management of, and responsibilities for test activities conducted during the program. The MTP incorporates the planning information for the program's integration and test events such as the Subsystem Integration Test, System Integration Test, User Acceptance Test and other applicable tests, in progressively higher levels of detail.

1.1.2 Scope

This MTP implements the Integration, Verification, and Validation process and identifies a set of I,V&V work products for the program. Identified herein are the specific activities, process elements, tasks, practices, and work products related to I,V&V. The schedule of these activities and the delivery of work products are captured in the program's Integrated Master Schedule (IMS). The program's IMS can be found in Appendix C.

1.2 MTP Overview

- Section 1 contains an overview of the MTP.
- Section 2 lists the applicable documents used in developing this MTP.
- Section 3 provides an overview of the system including a description of I,V&V specific hardware and software components.
- Section 4 describes the I,V&V Program, planning, control, and organization.
- Section 5 describes the element integration and verification activities.
- Section 6 describes the system integration, system verification and system validation activities including customer test events and customer collaboration.
- Section 7 contains the I,V&V support requirements, both the facilities and test equipment.

2 APPLICABLE DOCUMENTS

The following documents of the exact issue shown form a part of this plan to the extent specified herein.

2.1 Customer Documents

No.	ID	Title	Revision	Date
1.	TBS	TBS		
2.	TBS	TBS		

2.2 Lockheed-Martin Documents

No.	ID	Title	Revision	Date
1.	TBS	OTEC Pilot Plant Top Level Requirements		
2.	TBS	OTEC Pilot Plant System Specification		
3.	TBS	Platform Segment (Sub-System) Specification		
4.	TBS	Topsides Element Specification		
5.	TBS	Hull Element Specification		
6.	TBS	Station keeping Element Specification		
7.	TBS	Tensioning Sub-System (Assembly) Specification		
8.	TBS	Tension Members Sub-System (Assembly) Specification		
9.	TBS	Seafloor Anchors Sub-System (Assembly) Specification		
10.	TBS	Power Generation Segment (Sub-System) Specification		
11.	TBS	Power Cycle Element Specification		
12.	TBS	Hull Sub-System (Assembly) Specification		
13.	TBS	Working Fluid/Ammonia Sub-System (Assembly) Specification		
14.	TBS	Warm Water Sub-System (Assembly) Specification		
15.	TBS	Cold Water Sub-System (Assembly) Specification		
16.	TBS	Cold Water Pipe Element Specification		
17.	TBS	Pipe Sub-System (Assembly) Specification		
18.	TBS	Connection Sub-System (Assembly) Specification		
19.	TBS	Termination Sub-System (Assembly) Specification		
20.	TBS	Electrical Generation Element Specification		
21.	TBS	Turbine Sub-System (Assembly) Specification		
22.	TBS	Generator Sub-System (Assembly) Specification		
23.	TBS	Power Delivery Segment (Sub-System) Specification		
24.	TBS	Electrical Delivery Element Specification		
25.	TBS	Platform Substation Sub-System (Assembly) Specification		
26.	TBS	Power Transmission Sub-System (Assembly) Specification		
27.	TBS	On-Shore Substation Sub-System (Assembly) Specification		
28.	TBS	Integrated Instrumentation and Control Segment		

		(Sub-System) Specification
29.	TBS	Platform Management Element Specification
30.	TBS	Platform Instrumentation and Control Sub-System (Assembly) Specification
31.	TBS	Safety, Security, and Communication Instrumentation and Control Sub-System (Assembly) Specification
32.	TBS	Power (Cycle) Management Element Specification
33.	TBS	Power Cycle Instrumentation and Control Sub-System (Assembly) Specification
34.	TBS	Cold Water Pipe Instrumentation and Control Sub-System (Assembly) Specification
35.	TBS	Electrical Generation Instrumentation and Control Sub-System (Assembly) Specification
36.	TBS	Electrical Delivery Instrumentation and Control Sub-System (Assembly) Specification
37.	TBS	Environmental Monitoring Management Element Specification
38.	TBS	Instrumentation and Control Sub-System (Assembly) Specification
39.	TBS	Water Production Segment (Sub-System) Specification
40.	TBS	Cold Water Pipe Fabrication System Specification
41.	TBS	Cold Water Pipe Grip and Handling Segment (Sub-System) Specification
42.	TBS	Cold Water Pipe Fabrication Apparatus Segment (Sub-System) Specification
43.	TBS	Cold Water Pipe Fabrication Environmental Enclosure Segment (Sub-System) Specification
44.	TBS	Environmental Management System Specification
45.	TBS	Planning and Permitting Segment (Sub-System) Specification
46.	TBS	Operations and Monitoring Segment (Sub-System) Specification
47.	TBS	OTEC Installation System Specification
48.	TBS	Platform Installation Segment (Sub-System) Specification
49.	TBS	Power Generation Installation Segment (Sub-System) Specification
50.	TBS	Cold Water Pipe Installation Segment (Sub-System) Specification
51.	TBS	Power Delivery Installation Segment (Sub-System) Specification
52.	TBS	OTEC Decommissioning System Specification
53.	TBS	Platform Decommissioning Segment (Sub-System) Specification
54.	TBS	Power Generation Decommissioning Segment (Sub-System) Specification
55.	TBS	Cold Water Pipe Decommissioning Segment (Sub-System) Specification
56.	TBS	Power Delivery Decommissioning Segment

(Sub-System) Specification

2.3 Industry / Customer Standards

No.	ID	Title	Revision	Date
1.	API RP2 SK	Recommended Practice for Design and Analysis of Station Keeping Systems for Floating Structures	3rd Edition	Oct 2005
2.	API RP2 SM	Recommended Practices for Design, Manufacturing, Installation, and Maintenance Of Synthetic Fiber Ropes for Off Shore Mooring	1st Edition	Mar 2001
3.	ABS Guidance Notes	Application of Synthetic Ropes for Off Shore Mooring		Mar 1999
4.	ABS Class Rules	Class Rules for Floating Production Installations		
5.	ANSI B31.3	Ammonia Systems		
6.	ANSI B31.5	Ammonia Systems		
7.	ANSI K61.1	Ammonia Systems		

3 SYSTEM DESCRIPTION

Ocean Thermal Energy Conversion (OTEC) is an energy technology that converts solar radiation into electric power. OTEC systems use the ocean's natural thermal gradient (energy of the sun warms the surface of the ocean forming a temperature gradient from the warm surface waters to cold deep waters). This difference in temperature can be used to drive a power-producing cycle. A closed-cycle OTEC system uses warm surface seawater to vaporize ammonia (which has a low boiling point) which, in turn, drives turbines attached to electrical generators. The cold seawater is then used to condense ammonia back into a liquid which is then re-vaporized by the warm water. This process can produce a significant amount of power with little impact on the environment. The consistent flow of energy can be used to power commercial and residential needs. An OTEC plant has a (24/7) base load, near zero carbon emissions, and it can include fresh water production. Refer to Figure 3-1.

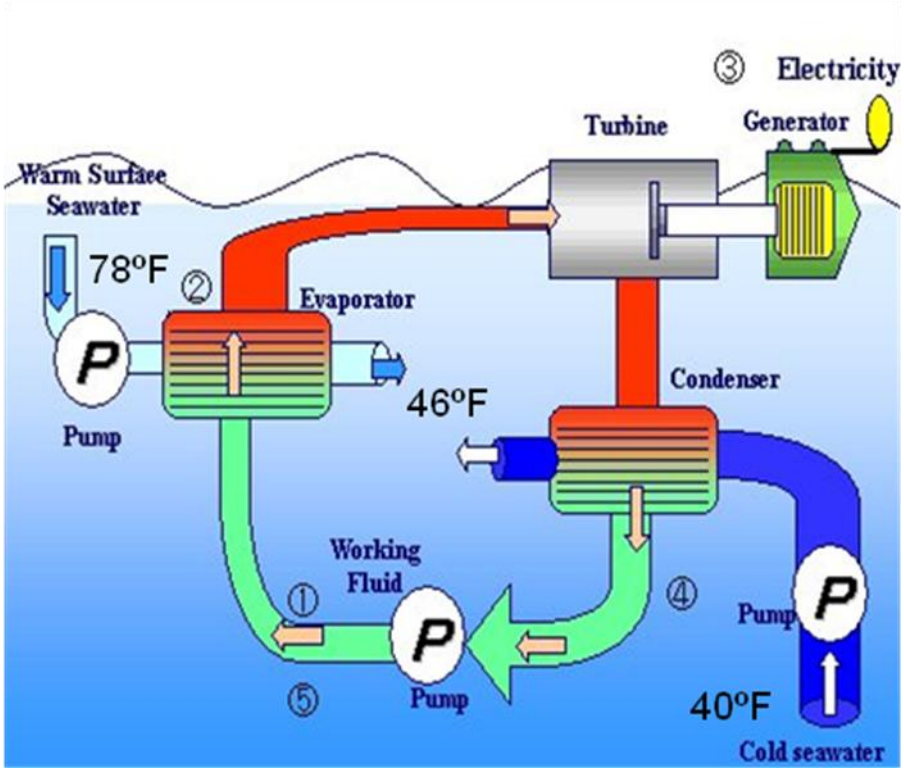


Figure 3-1 - Closed Cycle OTEC System

OTEC technology has been successfully demonstrated at a KW scale over the past 20 years. The next step is scaling up by a large factor. A 5-10MW Pilot Plant will first be produced and operated leading the way for a 100MW Commercial sized plant.

The OTEC Pilot Plant System of Systems (SoS) consists of five (5) Systems as follows:

1) The **OTEC Pilot Plant System** consists of the following five (5) Segments:

   a) Platform Segment

The Platform is comprised of deck and hull structures. Station-keeping (moorings and anchoring), Electrical plant, Communications & controls, Outfit & furnishing, and auxiliary systems are included as part of this sub-system.

b) Power Generation Segment

The Power Generation Segment contains the Power Cycle, Cold Water Pipe and Electrical Generation Elements.

The Power Cycle Element, referred to as a Remora, is a truss spar structure which is detachable from the Platform that contains the Heat Exchanger (Evaluators and Condensers) sub-systems, the working fluid (ammonia) sub-system, warm and cold seawater handling sub-systems (ducting, piping, valves & pumps), and the anti- corrosion and anti-bio-fouling sub-systems.

The Cold Water Pipe (CWP) element is a composite structure, 4m in diameter and approximately 1100 m in length and is constructed in-situ after the platform is on site. It contains a termination that employs trap-loc technology to allow for secure mounting of the pipe to the platform.

The Electrical Generation element contains the Turbine & Generator subsystem and associated support equipment.

c) Power Delivery Segment

The Power Delivery Segment contains the electrical power cable to shore (undersea and land portions), the platform substation with the electrical distributions system, and the on-shore electrical substation. The on-shore substation interfaces with the local electrical power grid.

d) Integrated Instrumentation & Control Segment

The Integrated Instrumentation and Control Segment provides monitoring and control for the Environmental, Performance, Health/Safety, Security, and Communication sub-sub-systems. A main control center will be the focal point and may include some local control capabilities. Each segment will contain instrumentation and controllers that interface via the main control center.

e) Water Production Segment

The Water Production Segment TBS.

2) The **OTEC Pilot Plant Cold Water Pipe Fabrication System** consists of the following three (3) major segments:

a) CWP Grip and Handling Segment

The Gripper/Handler mounts to the Platform's hull structure and holds and lowers the CWP during the fabrication process.

b) CWP Fabrication Apparatus Segment

The fabrication apparatus is the equipment used to manufacture the CWP. There are 3 major components/regions: the Core Assembly Region, the Fabric Placement Region and the Molding and VTRM/Resin Infusion Region.

c) CWP Fabrication Environmental Enclosure Segment

The Environmental Enclosure consists of the main structure which supports and protects the CWP Fab Apparatus as well as accommodations for material handling and related equipment.

These sub-systems are temporarily installed on the Platform during the manufacture of the CWP and are removed once the CWP is successfully deployed.

3) The **OTEC Pilot Plant Environmental Management System** consists of the following two (2) major segments:

   a) Planning & Permitting Segment

   b) Operations & Monitoring Segment

4) The **OTEC Pilot Plant Installation System** consists of the following four (4) major segments:

   The Installation and Checkout (INCO) System consists of the equipment, tools, processes and procedures needed to install, check-out and deploy the OTEC Pilot Plant at the designated site. The site selected is off the coast of Oahu Hawaii near Pearl Harbor. This will include installation of the Platform, Power cabling, and CWP, and for System Checkout.

   a) Platform Installation Segment

   b) Power Generation Installation Segment

   c) CWP Installation Segment

   d) Power Delivery Installation Segment

5) The **OTEC Pilot Plant Decommissioning System** consists of the following four (4) major segments:

   a) Platform Decommissioning Segment

   b) Power Generation Decommissioning Segment

   c) CWP Decommissioning Segment

   d) Power Delivery Decommissioning Segment

   The OTEC Pilot Plant System Functional Diagram is shown in Figure 3-2. These functions are allocated in the OTEC Pilot Plant System Logical Architecture diagram is shown in Figure 3-3.

TBS

Figure 3-2 – OTEC Pilot Plant Functional Diagram

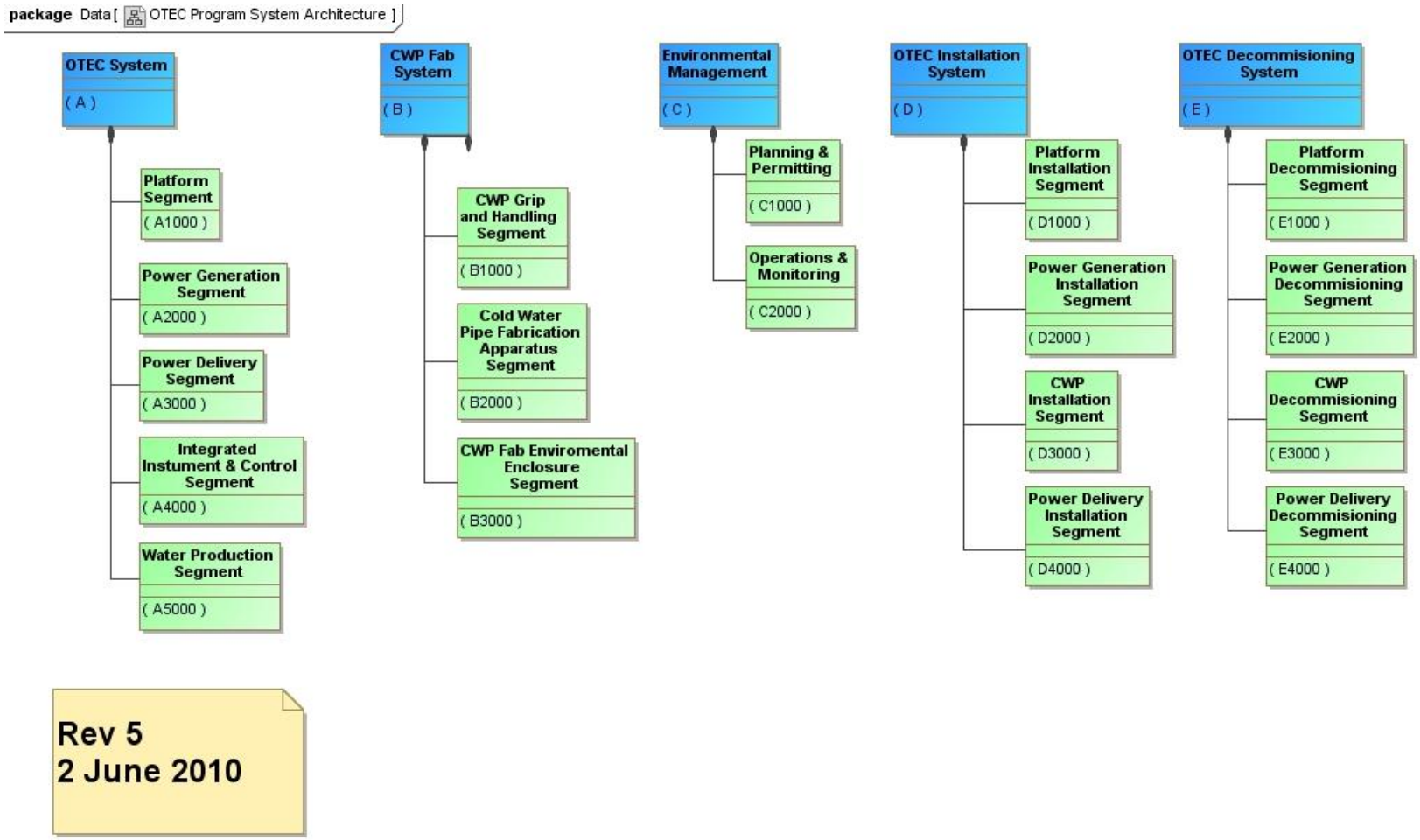


Figure 3-3 – OTEC Pilot Plant System Logical Architecture (1 of 2)

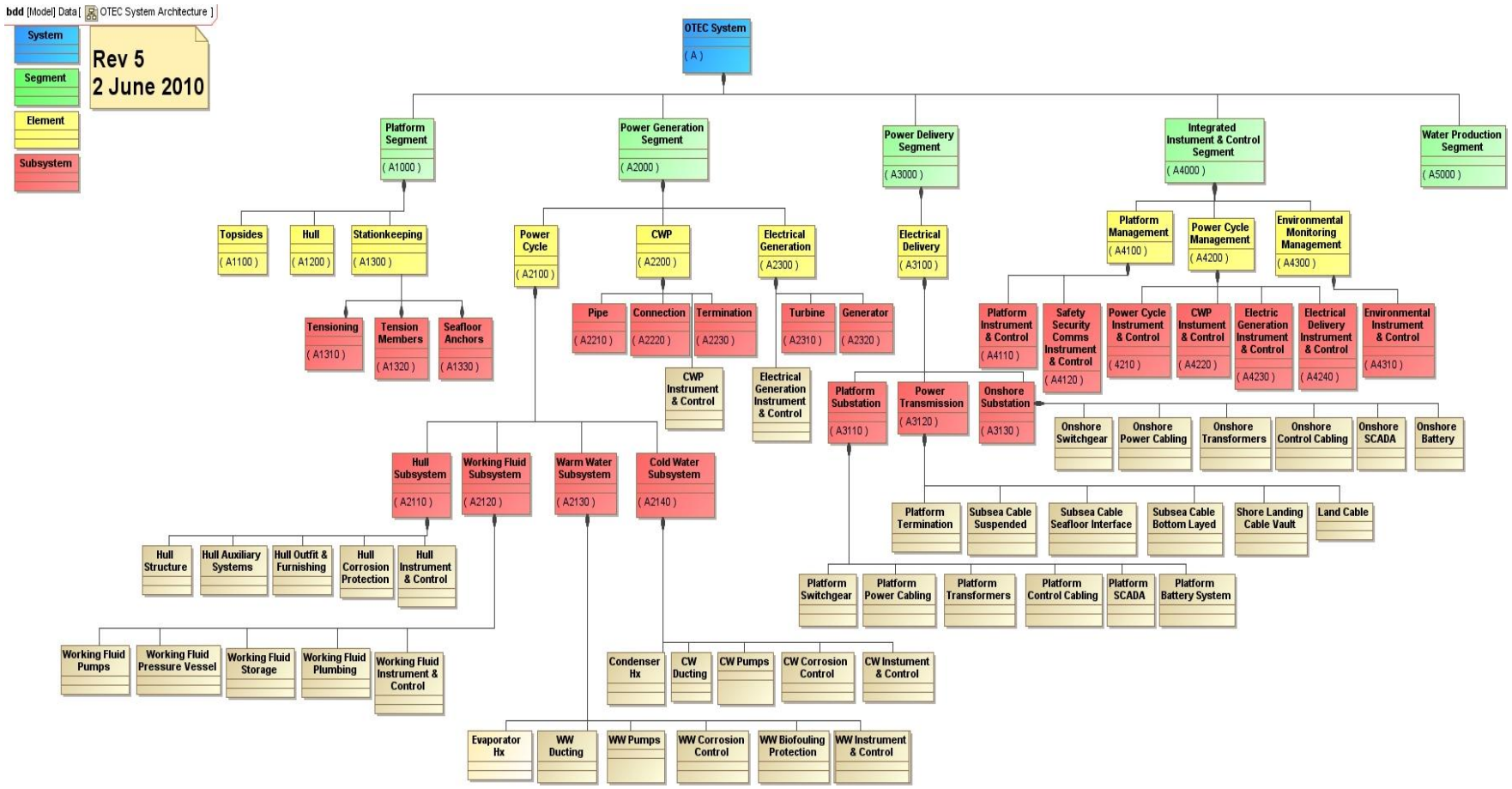


Figure 3-3 – OTEC Pilot Plant System Logical Architecture (2 of 2)

3.1 System/Hardware Overview

The OTEC Pilot Plant consists of the following sub-systems and components:

3.1.1 Platform Segment

The Platform Structure is a floating, moored, semi-submersible vessel that is the base for the OTEC Pilot Plant.

3.1.1.1 Topsides Element

The Topsides Structure consists of upper and lower decks outfitted and furnished with Sub-Systems/Assemblies such as Electrical Plant, Communication and Controls Systems, Safety Systems, and other services.

All integration and testing will be accomplished at the Shipbuilder's location and quay-side near the Pilot Plant site.

3.1.1.2 Hull Element

The Hull Structure consists of columns, pontoon, keel and other structural members.

All integration and testing will be accomplished at the Shipbuilder's location and quay-side near the Pilot Plant site.

3.1.1.3 Station-keeping Element

The Station-keeping sub-system consists of tensioning, tension members, and seafloor anchoring subsystems which keep the Platform at the selected site. Final integration and testing will be accomplished once the Pilot Plant is moved to the deployment site as part of the Installation and Check-out (INCO) activities.

- Tensioning subsystem

  TBS

- Tension Members subsystem

  TBS

- Seafloor Anchoring subsystem

  TBS

3.1.2 Power Generation Segment (Remora)

3.1.2.1 Power Cycle Element

- Heat Exchangers (Evaporators and Condensers) subsystem

  The Heat Exchangers sub-system consists of Evaporators and Condensers. There are 16 cores in the Evaporator assembly which causes the Working Fluid (WF) (ammonia) to boil when heated by the warm surface ocean water producing a vapor to spin the turbine. There are 2 Condenser units which cools the WF vapor and returns it to liquid form so it can be pumped back through the Evaporator.

  The Heat Exchanger units will be Factory Acceptance Tested (FAT) prior to delivery from the vendor. Integration and testing of the Heat Exchangers with the other systems will be

accomplished quay-side to the extent feasible. Final integration and testing will occur only once the Remora is at sea and in the vertical (deployed) orientation.

- Working Fluid (Ammonia) sub-system

  The Working Fluid (WF) sub-system consists of ammonia storage receptacles (located on deck), interconnect piping, control valves, feed pumps, screens & filters, and anti- corrosion assemblies. The WF passes through the Condenser cooling the ammonia vapor to a liquid to allow circulation through the WF sub-system. The WF is routed from the reservoir via piping through the Hxs and turbine. This is a closed system. Ammonia storage and sub-system charging takes place from facilities on deck.

  The WF sub-system components are FAT'ed at the vendor prior to delivery. Integration and testing of this sub-system will occur TBD.

- Cold Seawater Handling sub-system

  The Cold Water (CW) Handling sub-system consists of ducting, piping, valves, pumps, screens & filters, and & anti-bio-fouling assemblies. The CW passes through the Condenser cooling the ammonia vapor to a liquid to allow circulation through the WF sub-system. The CW is routed from the CWP via ducting to the Remora inlet port is piped through the Condensers and is discharged at the lower end of the Remora.

  The CW sub-system components are FAT'ed at the vendor prior to delivery. Integration and testing of this sub-system will occur TBD.

- Warm Seawater Handling sub-system

  The Warm Water (WW) Handling sub-system consists of ducting, piping, valves anti- corrosion and anti-bio-fouling, screens & filters. The WW passes through the Evaporator heating the ammonia liquid to a vapor. The WW is routed from the WW inlet port piped through the Evaporators and is discharged at the lower end of the Remora.

  The WW sub-system components are FAT'ed at the vendor prior to delivery. Integration and testing of this sub-system will occur TBD.

- Truss Spar (Hull) structure subsystem

  The Truss Spar structure sub-system consists of Hard and Soft Tanks, Trusses, braces, and equipment foundations/mounting provisions. Provisions for WW storage, Towing, and Handling are also included.

  This structure will be integrated and tested at the Shipyard prior to delivery. Installation of the various equipments and components will take place TBD. Final testing will take place once the Remora is at sea and in the vertical (deployed) orientation.

3.1.2.2 Cold Water Pipe Element

The CWP consists of the CWP main body, a Connection (to the Platform), and a Termination section that allows for interfacing and securing to the Platform Hull Structure.

- Cold Water Pipe (CWP) subsystem

  TBS

- Cold Water Pipe Connection subsystem

  TBS

- Cold Water Pipe Termination subsystem

  TBS

  CWP structural and material testing occurs during Engineering Acceptance/Design Verification testing at a LBTS at LM-SSC in Sunnyvale CA. Integration and testing of the CWP takes place at Sea while the Pipe is being manufactured and deployed.

3.1.2.3 Electrical Generation Element

The Electrical Generation element consists of a turbine-generator set that is delivered from the factory as a single unit.

FATing of the Turbine-Generator and related components will take place at the vendor's site prior to delivery. Integration and testing will take place TBD.

- Turbine subsystem

  The Turbine sub-system consists of TBS. The turbine is driven by ammonia vapor produced by the Evaporators located inside the Remora. The turbine is connected to one of more electrical generators which produce electricity.

- Generator subsystem

  The main electrical power Generator is connected to the Turbine and produces electricity once the system is operating.

  Additional generators, for auxiliary power, consist of a start up diesel generator for the initial system start-up and an auxiliary diesel generator as a back-up. These are part of the Platform Auxiliaries subsystem..

3.1.3 Power Delivery Segment

3.1.3.1 Electrical Delivery Element

- Electrical Power Transmission cable(s) subsystem

  The Power Transmission subsystem consists of a platform termination, subsea suspended cable, subsea seafloor cable, subsea bottom layed cable, a land cable, and a shore landing vault.

  The components of the Power Transmission subsystem components will be FAT'ed individually at the vendor's site prior to delivery. Initial integration and testing will take place TBD. The cabling will then be installed/deployed and checked-out. Integration and testing and interfacing to the platform and on-shore substations will take place TBD.

- Platform substation & electrical power distribution subsystem

  The Platform substation and electrical power distribution sub-system consists of switchgear, power and control cabling, transformers, Supervisory Control and Data Acquisition (SCADA), and batteries. The Platform distribution system consists of medium & low voltage

power which provides power to the electrical pumps. And to the central control station, system lighting, etc.

The components of the Platform substation will be FAT'ed at the vendor's site prior to delivery. Integration and testing will take place TBD. The components of the Platform Power distribution subsystem will be FAT'ed at the vendor's site prior to delivery. Integration and testing will take place TBD.

- On-shore electrical substation subsystem

The on-shore electrical substation sub-system consists of switchgear, power and control cabling, transformers, SCADA, and batteries. This substation provides the interface between the OTEC Pilot Plant and the local on-shore electrical power grid.

The components of the On-shore substation will be FAT'ed at the vendor's site prior to delivery. Integration and testing will take place TBD.

3.1.4 Integrated Instrumentation & Control Segment

3.1.4.1 Platform Management Element

- Platform Instrumentation & Control subsystem

The Platform Control sub-system consists of instrumentation & monitoring equipment, controllers, cabling, electronics cabinets and display consoles, software, and TBS.

These components will be FAT'ed at the vendor's site prior to delivery. Integration and testing will take place TBD.

- Safety, Security, Communication Instrumentation &Control subsystem

The Safety/Health Control sub-system consists of instrumentation & monitoring equipment, controllers, cabling, electronics cabinets and display consoles, software, and TBS.

The Security Control sub-system consists of instrumentation & monitoring equipment, controllers, cabling, electronics cabinets and display consoles, software, and TBS.

The Communication sub-system consists of instrumentation & monitoring equipment, controllers, cabling, electronics cabinets and display consoles, software, and TBS.

These components will be FAT'ed at the vendor's site prior to delivery. Integration and testing will take place TBD.

3.1.4.2 Power (Cycle) Management Element

- Power Cycle Instrumentation & Control subsystem

The Power Cycle Instrumentation & Control sub-system consists of instrumentation & monitoring equipment, controllers, cabling, electronics cabinets and display consoles, software, and TBS.

The components of the Power Cycle Instrumentation & Control sub-system will be FAT'ed at the vendor's site prior to delivery. Integration and testing will take place TBD.

- CWP Instrumentation & Control subsystem

The Cold Water Pipe (CWP) Instrumentation & Control sub-system consists of instrumentation & monitoring equipment, controllers, cabling, electronics cabinets and display consoles, software, and TBS.

The components of the CWP Instrumentation & Control sub-system will be FAT'ed at the vendor's site prior to delivery. Integration and testing will take place TBD.

- Electrical Generation Instrumentation &Control subsystem

The Electrical Generation Instrumentation &Control sub-system consists of instrumentation & monitoring equipment, controllers, cabling, electronics cabinets and display consoles, software, and TBS.

The components of the Electrical Generation Instrumentation & Control sub-system will be FAT'ed at the vendor's site prior to delivery. Integration and testing will take place TBD.

- Electrical Delivery Instrumentation &Control subsystem

The Electrical Delivery Instrumentation &Control sub-system consists of instrumentation & monitoring equipment, controllers, cabling, electronics cabinets and display consoles, software, and TBS.

The components of the Electrical Delivery Instrumentation &Control sub-system will be FAT'ed at the vendor's site prior to delivery. Integration and testing will take place TBD.

3.1.4.3 Environmental Monitoring Management Element

- Environmental Instrumentation &Control subsystem

The Environmental Instrumentation & Control sub-system consists of instrumentation & monitoring equipment, controllers, cabling, electronics cabinets and display consoles, software, and TBS.

The components of the Environmental Instrumentation & Control sub-system will be FAT'ed at the vendor's site prior to delivery. Integration and testing will take place TBD.

3.2 Cold Water Pipe (CWP) Fabrication System

3.2.1 Fabrication Apparatus Segment

The CWP Fabrication Apparatus sub-system consists of the Core Assembly Region, the Fabric Dispensing/Handling Region, VTRM/Resin Injection/Molding Region, and the tower/supporting structure. Theses sub-systems work together in sequence to fabricate TBS feet of composite CWP at a time. Each region is installed on the Tower/Support structure.

The components of the Fabrication Apparatus sub-system will be individually FAT'ed at the vendor's site prior to delivery and functionally tested at the LBTS at LM-SSC. Integration and testing will take place quay-side and at sea to produce several portion of CWP for analysis and evaluation. Final testing and acceptance will take place at sea once the Pilot Plant is located at the deployment site.

3.2.2 Environmental Enclosure Segment

The CWP Environmental Enclosure sub-system consists of the enclosure panel, support structures, material handling assemblies, and environmental control and safety systems. This sub-system encloses the Fabrication Apparatus used to manufacture the CWP.

The components of the Tower/Support sub-system will be FAT'ed at the vendor's site prior to delivery. Integration and testing will take place TBD. Final testing and acceptance will take place at sea once the Pilot Plant is located at the deployment site.

3.2.3 CWP Gripper/Handler Segment

The CWP Gripper/Handler sub-system consists of TBS. This sub-system holds the CWP in place and advances completed portions during the manufacture of the CWP.

The components of the Gripper/Handler sub-system will be FAT'ed at the vendor's site prior to delivery. Integration and testing will take place TBD. Final testing and acceptance will take place at sea once the Pilot Plant is located at the deployment site.

3.3 Computer Programs/Software Overview

The Integrated Instrumentation and Control System will contain several software application functioning together:

3.3.1 Platform Controls SW Applications

3.3.1.1 TBD1

This SW element TBS.

Integration and testing of this SW will take place TBD.

3.3.1.2 TBD2

This SW element TBS.

Integration and testing of this SW will take place TBD.

3.3.1.3 TDB3

This SW element TBS.

Integration and testing of this SW will take place TBD.

3.3.2 OTEC Controls SW Applications

3.3.2.1 TBD1

This SW element TBS.

Integration and testing of this SW will take place TBD.

3.3.2.2 TBD2

This SW element TBS.

Integration and testing of this SW will take place TBD.

3.3.3 Other SW Applications

3.3.3.1 TBD1

This SW element TBS.

Integration and testing of this SW will take place TBD.

3.3.3.2 TBD2

This SW element TBS.

Integration and testing of this SW will take place TBD.

3.4 I,V&V Equipment Overview

3.4.1 Integration

Integration efforts will be undertaken as parts/components are assembled together to form the next higher level assembly as defined in the physical architecture and whose interface is described in the associated Interface Specifications or requirements. Many of these activities will be carried out at a LBTS. Due to the nature and size of the Pilot Plant Sub-systems some activities cannot take place until the system is assembled quay-side or may even have to wait until the system is at sea.

Specific Integration equipment and environments are: TBD.

3.4.2 Integration, Test & Evaluation

Integration, Test & Evaluation activities will take place once integration efforts are completed to verify that the product/sub-system/system meets its defined requirements. Some of these can take place at a LBTS and others must wait until the system is assembled quay-side or may even have to wait until the system is at sea.

Specific Integration, Test, and Evaluation equipment and environments are: TBD.

3.4.3 Installation and Checkout (INCO)

INCO activities will begin as the system segments and elements are assembled quay-side and will continue until the system is in place at the site location and is fully operational and ready to connect to the local Power Grid. The major components to be installed are the Platform, Power Cable, and CWP. Once installation and integration is complete, a System Checkout or Verification testing will be performed.

Specific INCO equipment and tools are: TBD.

3.4.4 Validation

Validation activities are usually planned to take place at the end of the deployment phase and controller and conducted by the customer organization with contractor assistance. We have planned to perform validation activities at several points earlier in the test program to give the customer more insight into progress along the way. These activities/events are: TBD. The system and sub-system requirements and the operational scenarios developed form the system CONOPS will be used to conduct theses tests/events.

Specific Integration, Test, and Evaluation equipment and environments are: TBD.

4 I,V&V PROGRAM PLANNING, CONTROL, AND ORGANIZATION

4.1 I,V&V Program Planning

The I,V&V Process activity for the OTEC Pilot Plant program starts with System Definition, Design, and Development, and concludes with the completion of the Pilot Plant to Grid Interface Acceptance Test. I,V&V planning entails the identification of I,V&V activities, the allocation of resources to these activities, and the relationship of these activities with key program milestones. The I,V&V Significant Accomplishments, Work Breakdown Structure (WBS), resource allocations, and roles and responsibilities are defined in the program's PMP-NRE. The program's Lead Integration & Test (I&T) Engineer is responsible for defining I,V&V activities and collaborating with the program's master planner/scheduler to incorporate I,V&V activities into the program's master plan / schedule, and supporting the program's risk/opportunity manager in identifying I,V&V risks/opportunities.

The IV&V Team is part of the System Engineering and Integration & Test (SEI&T) Integrated Product Team (IPT) as described in Figure 4.1-1, OTEC Organizational Diagram.

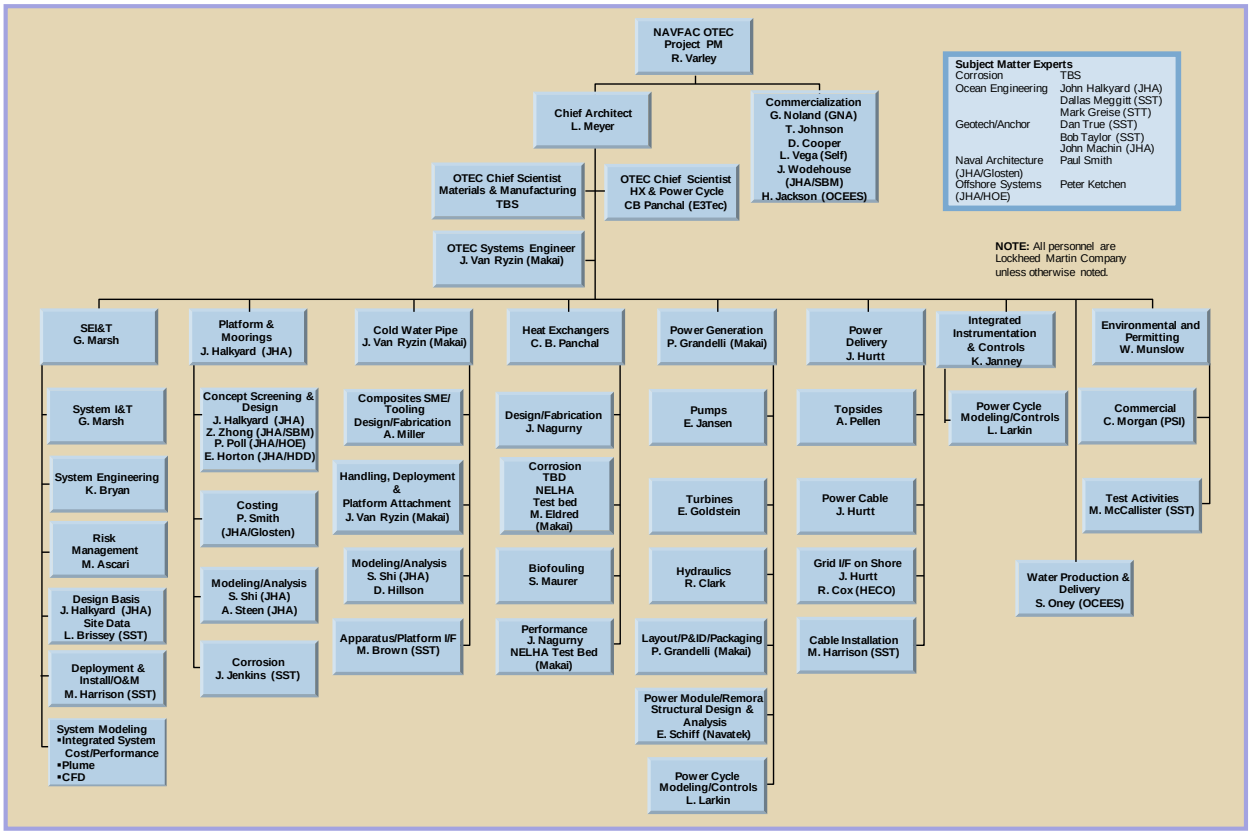


Figure 4.1-1 – OTEC Organizational Chart

4.2 I,V&V Program Control

The Lead Integration & Test (I&T) Engineer is responsible for managing the cost, schedule, and execution of the program's I,V&V activities. The Lead I&T Engineer will interface and coordinate with External Customers and Stakeholders, the program's Engineering Project Manager (EPM), Program Manager, and LM Partners as needed and required throughout the I,V&V program to discuss and obtain concurrence and approval for the following areas of I,V&V program control.

- Changes or Waivers to the I,V&V program objectives or requirements
- Concurrence of planned I,V&V Milestones
- Changes to I,V&V program Schedule

4.3 I,V&V Program Organization

The Lead I&T Engineer is the Responsible Individual (RI) for the overall I,V&V Program. The Lead I&T Engineer ensures that planned I,V&V activities are sufficient for the program and that work products meet specified requirements and are completed per the program schedule. The Lead I&T Engineer interfaces with the Customer, LM Partners and LM Subcontractors to ensure that the work products from LM, LM Partners and LM Subcontractors are performed in accordance with defined processes, and are completed in accordance with the program's master schedule. The program's I,V&V organization is detailed in the program's PMP-NRE and is depicted in Figure 4.3-1 OTEC Pilot Plant IV&V Organization.

TBS

Figure 4.3-1 – OTEC Pilot Plant IV&V Organization Diagram

4.3.1 External I,V&V Program Organizations

4.3.1.1 Customer & Stakeholder Test Organizations

- US Department of Energy (DoE)
- US Department of Defense (DoD)
- US Naval Facilities Command (NAVFAC) (DoD)
- US National Oceanographic & Atmospheric Administration (NOAA)
- US Environmental Protection Agency (EPA)

- American Bureau of Shipping (ABS)
- US Coast Guard (USCS)

4.3.1.2 LM Partner(s) Test Organization

- E^3TEC Service, LLC
- Florida State University (FSU)
- Gary Noland Associates, Inc.
- The Glosten Associates
- Hawaii Natural Energy Institute (HNEI) [University of Hawaii]
- Hawaiian Electric Company (HECO)
- Houston Off Shore Engineering (HOE)
- John Halkyard & Associates
- Dr. Louis A. Vega
- Makai Ocean Engineering
- Natural Energy Laboratory of Hawaii (NELHA)
- NAVATEK Ltd.
- Ocean Engineering and Energy Systems (OCEES) International, Inc.
- Planning Solution Incorporated (PSI)
- SBM Atlantia, Inc.
- Sea & Sound Technologies (SST)

4.3.1.3 Subcontractor Test Organization

- Glasforms, Inc.
- Janicki Industries
- Stress Engineering Services, Inc.
- TBS
- TBS
- TBS

5 ENGINEERING DEVELOPMENT INTEGRATION AND VERIFICATION PLAN

The purpose of this Engineering Development Test Plan is to document the integration and test of items and subsystems to assess and investigate various approaches and equipments to assist with design selections and decisions and build the next higher-level subsystem. This is Informal testing which is planned and carefully documented. The ED phase culminates with a set of data and results that help solidify component designs.

5.1 Engineering Development Hardware Integration and Verification

Power Generation Segment

5.1.1 Heat Exchanger Corrosion Control Engineering Development Testing [LM]

1) Test Objectives

- Primary

  Evaluate Condensers and Evaporators of varying materials designs to assess the Corrosion susceptibility characteristics of each.

- Secondary

  a. Assess Technical performance of the Heat Exchangers

  b. Collect performance data under varying and controlled circumstances

2) Test Description

This test will consist of placing selected Heat Exchangers into a lab environment and operating them together under varying temperature conditions.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a) Test Plan completed, reviewed and approved
b) Test Procedures completed, reviewed and approved.
c) Lab construction and checkout completed and approved for use
d) FAT completed for each of the Heat Exchangers
e) Dry Runs completed
f) Successful completion of the Heat Exchanger Evaluation TRR

4) Test Schedule & Location

This test is scheduled to be performed at the LM-MS2 Heat Exchanger Test Facility in Manassas VA in the 3rd and 4th Qtrs of 2010.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test:

ITEM	DESCRIPTION	FUNCTION	QTY
1	Condenser	Unit Under Test (UUT)	AR
2	Evaporator	Unit Under Test	AR

ITEM	DESCRIPTION	FUNCTION	QTY
3	Water Pumps	Support equipment	AR
4	Environment Data Acquisition System (DAS)	Test equipment	1
5	Sensors & Instruments	Test equipment	AR
6	Heat Exchangers Plumbing (Piping, ducting and valves)	Support equipment	AR
7	Working Fluid System (Plumbing, pumps, etc.)	Support equipment	AR
8	Corrosion Control System	UUT	AR

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Condensers and Evaporators Corrosion Control ED Test Plan		
Condensers and Evaporators Corrosion Control ED Test Procedures		
Condensers and Evaporators Corrosion Control ED Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Heat Exchanger Test Plan.

5.1.2 Heat Exchanger Corrosion Control Engineering Development Testing [Makai]

1) Test Objectives

- Primary

  Evaluate Condensers and Evaporators of varying materials designs to assess the Corrosion susceptibility characteristics of each.

- Secondary

  a. Assess Technical performance of the Heat Exchangers

  b. Collect performance data under varying and controlled circumstances

2) Test Description

This test will consist of placing selected Heat Exchangers into a lab environment and operating them together under varying temperature conditions.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a) Test Plan completed, reviewed and approved
b) Test Procedures completed, reviewed and approved.

c) Lab construction and checkout completed and approved for use
d) FAT completed for each of the Hxs
e) Dry Runs completed
f) Successful completion of the Heat Exchanger Evaluation TRR

4) Test Schedule & Location

This test is scheduled to be performed at the NELHA Test Facility in Oahu HI in TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test:

ITEM	DESCRIPTION	FUNCTION	QTY
1	Condenser	Unit Under Test	AR
2	Evaporator	Unit Under Test	AR
3	Water Pumps	Support equipment	AR
4	Data Acquisition System	Test equipment	1
5	Sensors & Instruments	Test equipment	AR
6	Heat Exchangers Plumbing (Piping, ducting and valves)	Support equipment	AR
7	Working Fluid System (Plumbing, pumps, etc.)	Support equipment	AR
8	Corrosion Control System	UUT	AR

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Heat Exchangers Corrosion Control ED Test Plan		
Heat Exchangers Corrosion Control ED Test Procedures		
Heat Exchangers Corrosion Control ED Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Heat Exchanger Test Plan.

5.1.3 CWP Engineering Development Testing

1) Test Objectives

- Primary

  Evaluate CWP material strength and quality TBD.

- Secondary
  a. To validate the CWP Fabrication process for the Core Assembly Region.
  b. To validate the CWP Fabrication process for the Fabric Placement/Dispensing Region.
  c. To validate the CWP Fabrication process for the Molding/VRTM/Resin Infusion region.
  d. To validate the CWP Fabrication process for the in manufacturing short lengths of pipe and examining sections and coupons.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved
b. Test Procedures completed, reviewed and approved.
c. Lab construction and checkout completed and approved for use
d. FAT completed for each of the CWP Fabrication Apparatus
e. Dry Runs completed
f. Successful completion of the CWP Evaluation TRR

4) Test Schedule & Location

This test is scheduled to be performed at TBS Test Facility in TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	CWP representative sections	UUT	
2	CWP test coupons	UUT	
3	CWP test panels	UUT	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
CWP ED Test Plan		
CWP ED Test Procedures		
CWP ED Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the CWP Evaluation Test Plan.

CWP Fabrication System

5.1.4 CWP Gripper/Handler Engineering Development Testing

1) Test Objectives

- Primary

  Evaluate CWP Gripper/Handler design using scale models.

- Secondary

  a. Gripper holding properties, TBS.

  b. CWP handling when lowering, TBS.

  c. CWP stresses and bending moments, TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the Gripper/Handler System components

e. Dry Runs completed

f. Successful completion of the CWP Gripper/Handler TRR

4) Test Schedule & Location

This test will be conducted at the Makai Test Facility in Hawaii during the 3rd Quarter of 2010.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	CWP Gripper/Handler, scale model	UUT	1
2	CWP section, scale model	UUT	1
3	Platform representative mounting fixtures	Support equipment	1
4	Data Acquisition System (DAS)	Test equipment	1
5	Monitoring & Measuring Instruments	Test equipment	AR

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
CWP Gripper/Handler ED Test Plan		
CWP Gripper/Handler ED Test Procedures		
CWP Gripper/Handler ED Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the CWP Gripper/Handler System Test Plan.

5.1.5 CWP Attachment/Gimbal Engineering Development Testing

1) Test Objectives

- Primary

  Evaluate CWP Attachment/Gimbal design using scale models.

- Secondary

  a. TBS.

  b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	CWP Gripper/Handler, scale model		1
2	CWP section, scale model		1
3	CWP termination, scale model		1
4	Platform representative mounting fixtures		1
5	Data Acquisition System		1
6	Monitoring & Measuring Instruments		AR

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
CWP Attachment/Gimbal ED Test Plan		
CWP Attachment/Gimbal ED Test Procedures		
CWP Attachment/Gimbal ED Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the CWP Attachment/Gimbal Test Plan.

5.1.6 CWP Termination Engineering Development Testing

1) Test Objectives

- Primary

  Evaluate the feasibility of the proposed Termination design, using Analysis, Models and test sections.

- Secondary

  a. TBS.

  b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	CWP representative section	Support equipment	
2	CWP termination	UUT	
3	CWP Attachment/Gimbal representative section	Support equipment	
4	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
CWP Termination ED Test Plan		
CWP Termination ED Test Procedures		
CWP Termination ED Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

5.1.7 CWP Fabrication Apparatus Engineering Development Testing (Step 0)

1) Test Objectives

- Primary

  Verify the proposed design of the CWP Fabrication Apparatus meets the requirements in the TBS document(s).

- Secondary

  a. TBS.

  b. TBS.

2) Test Description

These tests consist of four tests that encompass the Core Assembly, Fabric Dispensing, Molding, and VTRM/Resin Infusion Regions which will be tested/evaluated individually. A fifth test is part of this series, Critical Restart and is covered separately.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components/regions

e. Dry Runs completed for each Region

f. Successful completion of each of the CWP Fabrication Apparatus Step 0 TRRs.

4) Test Schedule & Location

This test will be conducted at the LM SSC Building 142 Test Facility in Sunnyvale, CA during the 3rd and 4th Quarters of 2010.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Core Assembly Region & lifting fixture	UUT	
2	Shear Keys	material	
3	Core Planks	material	
4	Alignment Fixture	Support equipment	
5	Fabric Dispensing Region	UUT	
6	Fabric Rolls	material	
7	Molding Region	UUT	
8	Vacuum system	Support equipment	
9	VTRM/Resin Infusion Region	UUT	
10	Resin	material	
11	Resin catalyst	material	
12	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
CWP Fabrication Apparatus ED Test Plan		
CWP Fabrication Apparatus ED Test Procedures		
CWP Fabrication Apparatus ED Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

5.1.8 CWP Fabrication Apparatus Integration Engineering Development Testing (Step 1)

1) Test Objectives

- Primary

  Verify the integrated CWP Fabrication Apparatus meets the requirements in the TBS document(s).

- Secondary

  a. TBS.

  b. TBS.

2) Test Description

This test consists of integrating the four elements of the CWP Fabrication Apparatus (Core Assembly, Fabric Dispensing, Molding/VTRM/Resin Infusion Region, and Tower/Support structure) and operating and testing/evaluating them together to produce a section(s) of CWP.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the CWP Integrated Fabrication Apparatus (Step1) TRR.

4) Test Schedule & Location

This test will be conducted at the TBD Land-based or Quay-side Test Facility/Site in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Tower/Support Structure	UUT	
2	Core Assembly Region & lifting fixture	UUT	
3	Shear Keys	material	
4	Core Planks	material	
5	Alignment Fixture	Support equipment	
6	Fabric Dispensing Region	UUT	
7	Fabric Rolls	material	
8	Molding/VTRM/Resin Infusion Region	UUT	
9	Vacuum system	Support equipment	
10	Resin	material	
11	Resin catalyst	material	
12	Crane or material handling/lifting device	Support equipment	
13	TBS		
14	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
CWP Fabrication Apparatus Integration & Test Plan		
CWP Fabrication Apparatus Integration & Test Procedures		
CWP Fabrication Apparatus Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

5.1.9 CWP Fabrication Critical Restart Engineering Development Testing

1) Test Objectives

- Primary

  Verify the CWP Fabrication Apparatus capability to stop CWP fabrication and restart can be successfully demonstrated to meet the requirements in the TBS document(s).

- Secondary

  a. TBS.

  b. TBS.

2) Test Description

These tests consist of stopping and restarting CWP fabrication. This test will be piggybacked with the Step 1 test.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Tower/Support Structure	UUT	
2	Core Assembly Region & lifting fixture	UUT	
3	Shear Keys	material	
4	Core Planks	material	
5	Alignment Fixture	Support equipment	
6	Fabric Dispensing Region	UUT	
7	Fabric Rolls	material	
8	Molding/VTRM/Resin Infusion Region	UUT	
9	Vacuum system	Support equipment	
10	Resin	material	
11	Resin catalyst	material	
12	Crane or material handling/lifting device	Support equipment	
13	TBS		
14	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
CWP Fabrication Critical Restart ED Test Plan		
CWP Fabrication Critical Restart ED Test Procedures		
CWP Fabrication Critical Restart ED Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

5.1.10 CWP Fabrication Environmental Enclosure HVAC Engineering Development Testing

1) Test Objectives

- Primary

  Verify the proposed design for the CWP Fabrication Environmental Enclosure HVAC meets the requirements in the TBS document(s).

- Secondary

  a. TBS.

  b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	HVAC components	UUT	
2	Representative Environmental Enclosure	Support equipment	
3	Event DAS	Test equipment	
4	Environment DAS	Test equipment	
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
CWP Fabrication Environmental Enclosure HVAC ED Test Plan		
CWP Fabrication Environmental Enclosure HVAC ED Test Procedures		
CWP Fabrication Environmental Enclosure HVAC ED Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

5.1.11 CWP Fabrication Environmental Enclosure Fabric Handling Engineering Development Testing

1) Test Objectives

- Primary

  Verify the proposed design for the CWP Fabrication Environmental Enclosure fabric handling assembly meets the requirements in the TBS document(s).

- Secondary

  a. TBS.

  b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Fabric roll handling components	UUT	
2	Fabric rolls	Support equipment	
3	Representative Environmental Enclosure	Support equipment	
4	Environment DAS	Test equipment	
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
CWP Fabrication Environmental Enclosure Fabric Dispensing ED Test Plan		
CWP Fabrication Environmental Enclosure Fabric Dispensing ED Test Procedures		
CWP Fabrication Environmental Enclosure Fabric Dispensing ED Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

5.1.12 CWP Fabrication Environmental Enclosure Air Handling Engineering Development Testing

1) Test Objectives

- Primary

  Verify the proposed design for the CWP Fabrication Environmental Enclosure air handling assembly meets the requirements in the TBS document(s).

- Secondary

  a. TBS.

  b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Air handling components (intake, filtering & exhaust)	UUT	
2	Environment DAS	Test equipment	
3	Representative environmental enclosure	Support equipment	
4	TBS		
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
CWP Fabrication Environmental Enclosure Air Handling ED Test Plan		
CWP Fabrication Environmental Enclosure Air Handling ED Test Procedures		
CWP Fabrication Environmental Enclosure Air Handling ED Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

5.1.13 CWP Fabrication Environmental Enclosure Apparatus Core Plank Handling Engineering Development Testing

1) Test Objectives

- Primary

  Verify the proposed design for the CWP Fabrication Environmental Enclosure core plank handling assembly meets the requirements in the TBS document(s).

- Secondary

  a. TBS.

  b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Core plank handling components	UUT	
2	Core Planks	Support equipment	
3	Representative environmental enclosure	Support equipment	
4	DAS	Test equipment	
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
CWP Fabrication Environmental Enclosure Core		

DOCUMENT	RESPONSIBILITY	CDRL NO.
Plank Handling ED Test Plan		
CWP Fabrication Environmental Enclosure Core Plank Handling ED Test Procedures		
CWP Fabrication Environmental Enclosure Core Plank Handling ED Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

5.2 Engineering Development Software Integration and Verification

II&C Segment

5.2.1 Integrated Instrumentation and Controls (II&C) Software Engineering Development Testing

1) Test Objectives

- Primary

  Verify the proposed design for the II&C Software programs meet the requirements in the TBS document(s).

- Secondary

  a. TBS.

  b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	II&C Software	UUT	
2	II&C Host computer	Support equipment	
3	II&C Consoles and displays	Support equipment	
4	Segment I&C sensor simulator	Test/support equipment	
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
II&C Software ED Test Plan		
II&C Software ED Test Procedures		
II&C Software ED Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

5.3 Factory/Vendor Acceptance Tests (FAT)

The following components will undergo testing/certification at the suppliers location. These items are mainly Commercial Off-The-Shelf (COTS) or Modified Commercial Off-The-Shelf (MOTS) units. OTEC IV&V Team representatives may assist with development of test plans and procedures and may witness testing as appropriate.

Platform Segment

5.3.1 Platform Tensioning FAT

Verification that the Platform Tensioning Subsystem meets the requirements/specifications contained in the TBD document.

5.3.2 Platform Tension Members FAT

Verification that the Platform Tension Members Subsystem meets the requirements/specifications contained in the TBD document.

5.3.3 Platform Seafloor Anchors FAT

Verification that the Platform Seafloor Anchors Subsystem meets the requirements/specifications contained in the TBD document.

5.3.4 Platform Control Center System FAT

Verification that the Platform Control Center Subsystem meets the requirements/specifications contained in the TBD document.

5.3.5 Platform Lighting System FAT

Verification that the Platform Lighting Subsystem meets the requirements/specifications contained in the TBD document.

5.3.6 Platform Electrical (Pumps) System FAT

Verification that the Platform Electrical Subsystem (for the pumps) meets the requirements/specifications contained in the TBD document.

5.3.7 Platform Ammonia Storage System FAT

Verification that the Platform Ammonia Storage Subsystem meets the requirements/specifications contained in the TBD document.

Power Generation Segment

5.3.8 Remora Ammonia Pumps FAT

Verification that the Remora Ammonia pumps meet the requirements/specifications contained in the TBD document.

5.3.9 Remora Ammonia Demister FAT

Verification that the Remora Ammonia demister meets the requirements/specifications contained in the TBD document.

5.3.10 Remora Ammonia Reservoir FAT

Verification that the Remora Ammonia reservoir/buffer tanks meet the requirements/specifications contained in the TBD document.

5.3.11 Remora Ammonia Piping, Ducting & Valves FAT

Verification that the Remora Ammonia piping, ducting and valves meet the requirements/ specifications contained in the TBD document.

5.3.12 Remora Warm Water Pumps FAT

Verification that the Remora WW pumps meet the requirements/specifications contained in the TBD document.

5.3.13 Remora Warm Water Screens FAT

Verification that the Remora WW pumps meet the requirements/specifications contained in the TBD document.

5.3.14 Remora Warm Water Piping, Ducting & Valves FAT

Verification that the Remora WW piping, ducting and valves meet the requirements/ specifications contained in the TBD document.

5.3.15 Remora Cold Water Pumps FAT

Verification that the Remora CW pumps meet the requirements/ specifications contained in the TBD document.

5.3.16 Remora Cold Water Screens FAT

Verification that the Remora CW screens/filters meet the requirements/ specifications contained in the TBD document.

5.3.17 Remora Cold Water Piping, Ducting & Valves FAT

Verification that the Remora CW piping, ducting and valves meet the requirements/ specifications contained in the TBD document.

5.3.18 Electrical Generation Turbine-Generator Set FAT

Verification that the turbine-generator set meets the requirements/ specifications contained in the TBD document.

Power Delivery Segment

5.3.19 Platform/Electrical Generation Start-Up Diesel Generator FAT

Verification that the Start-up diesel generator meets the requirements/ specifications contained in the TBD document.

5.3.20 Platform/Electrical Generation Auxiliary Diesel Generator FAT

Verification that the Auxiliary diesel generator meets the requirements/ specifications contained in the TBD document.

5.3.21 Platform Substation Switchgear FAT

Verification that the Platform Substation Switchgear meets the requirements/ specifications contained in the TBD document.

5.3.22 Platform Substation Transformers FAT

Verification that the Platform Substation Transformers meet the requirements/ specifications contained in the TBD document.

5.3.23 Platform Substation Batteries FAT

Verification that the Platform Substation Batteries meets the requirements/ specifications contained in the TBD document.

5.3.24 Platform Substation Power Cabling FAT

Verification that the Platform Substation power cabling meets the requirements/ specifications contained in the TBD document.

5.3.25 Platform Substation SCADA FAT

Verification that the Platform Substation SCADA components meet the requirements/ specifications contained in the TBD document.

5.3.26 Platform Substation Control Cabling FAT

Verification that the Platform Substation control cabling meets the requirements/ specifications contained in the TBD document.

5.3.27 Power Transmission Land Cable FAT

Verification that the Power transmission land cable meets the requirements/ specifications contained in the TBD document.

5.3.28 Power Transmission Undersea Suspended Cable FAT

Verification that the Power transmission undersea suspended cable meets the requirements/ specifications contained in the TBD document.

5.3.29 Power Transmission Undersea Seafloor Cable FAT

Verification that the Power transmission undersea seafloor cable meets the requirements/ specifications contained in the TBD document.

5.3.30 Power Transmission Undersea Bottom Layed Cable FAT

Verification that the Power transmission undersea bottom layed cable meets the requirements/ specifications contained in the TBD document.

5.3.31 Power Transmission Shore Landing Cable Vault FAT

Verification that the Power transmission shore landing cable vault meets the requirements/ specifications contained in the TBD document.

5.3.32 On-Shore Substation Switchgear FAT

Verification that the On-Shore Substation Switchgear meets the requirements/ specifications contained in the TBD document.

5.3.33 On-Shore Substation Transformers FAT

Verification that the On-Shore Substation Transformers meet the requirements/ specifications contained in the TBD document.

5.3.34 On-Shore Substation Batteries FAT

Verification that the On-Shore Substation batteries meets the requirements/ specifications contained in the TBD document.

5.3.35 On-Shore Substation Power Cabling FAT

Verification that the On-Shore Substation power cabling meets the requirements/ specifications contained in the TBD document.

5.3.36 On-Shore Substation SCADA FAT

Verification that the On-Shore Substation SCADA component meets the requirements/ specifications contained in the TBD document.

5.3.37 On-Shore Substation Control Cabling FAT

Verification that the Platform Substation control cabling meets the requirements/ specifications contained in the TBD document.

6 SUBSYSTEM INTEGRATION AND VERIFICATION PLAN

The purpose of this Subsystem Integration and Test Plan is to document the integration and test of items and subsystems to build the specified next higher-level element. Informal testing will occur at each level of integration. The element integration and test phase culminates with a high-level element that is ready for formal qualification testing.

6.1 Subsystem Hardware Integration and Verification

Platform Segment

6.1.1 Platform Station keeping Tensioning Subsystem Integration & Test

1) Test Objectives

- Primary

  Verify the Station keeping Tensioning meets the requirements of the TBS document(s).

- Secondary

a. TBS

b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Tensioning	Unit Under Test	
2	Platform/Hull representative fixture	Test Equipment	
3	Data Acquisition System	Test Equipment	
4	Monitoring & Measuring Instruments	Test Equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Station keeping Tensioning Integration & Test Plan		
Station keeping Tensioning Integration & Test Procedures		
Station keeping Tensioning Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.2 Platform Station keeping Tension Members Subsystem Integration & Test

1) Test Objectives

- Primary

  Verify the Station keeping Tension Members meet the requirements of the TBS document(s).

- Secondary

a. TBS

b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Tension Members	Unit Under Test	
2	Platform/Hull representative fixture	Test Equipment	
3	Data Acquisition System	Test Equipment	
4	Monitoring & Measuring Instruments	Test Equipment	
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Station keeping Tension Members Integration & Test Plan		
Station keeping Tension Members Integration & Test Procedures		
Station keeping Tension Members Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.3 Platform Station keeping Seafloor Anchors Subsystem Integration & Test

1) Test Objectives

- Primary

  Verify the Station keeping Seafloor Anchors meet the requirements of the TBS document(s).

- Secondary

a. TBS

b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Anchors	Unit Under Test	
2	Platform/Hull Mooring representative fixtures	Test Equipment	
3	Data Acquisition System	Test Equipment	
4	Monitoring & Measuring Instruments	Test Equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Station keeping Seafloor Anchors Integration & Test Plan		
Station keeping Seafloor Anchors Integration & Test Procedures		
Station keeping Seafloor Anchors Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

Power Generation Segment

6.1.4 Condenser (Cold Water Handling) Subsystem Integration and Test

2) Test Objectives

- Primary

Verify the Condenser/Cold Water Handling Subsystem meets the requirements of the TBS document(s).

- Secondary
  a. TBS
  b. TBS

3) Test Description

This test consists of TBS.

4) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved
b. Test Procedures completed, reviewed and approved.
c. Lab construction and checkout completed and approved for use
d. FAT completed for each of the components
e. Dry Runs completed
f. Successful completion of the TRR

5) Test Schedule & Location

This test will be conducted at TBS.

6) Test Configuration

TBS.

7) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Condensers	UUT	AR
2	Interconnect piping	Support equipment	AR
3	Manifolds	Support equipment	AR
4	Water Supply		
5	Water Pumps		
6	Instrumentation	Test equipment	
7	DAS	Test equipment	
8	Simulated Ammonia circulation system	Test equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
CW Handling Subsystem Integration & Test Plan		

CW Handling Subsystem Integration & Test Procedures		
CW Handling Subsystem Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.5 Evaporator (Warm Water Handling) Subsystem Integration and Test

1) Test Objectives

- Primary

  Verify the Evaporator/Warm Water Handling Subsystem meets the requirements of the TBS document(s).

- Secondary

a. TBS

b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Evaporators	UUT	AR
2	Interconnect piping	Support equipment	AR
3	Manifolds	Support equipment	AR
4	Water Supply		
5	Water Pumps		
6	Instrumentation	Test equipment	
7	DAS	Test equipment	
8	Simulated Ammonia circulation system	Test equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
WW Handling Subsystem Integration & Test Plan		
WW Handling Subsystem Integration & Test Procedures		
WW Handling Subsystem Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.6 Ammonia (Working Fluid) Handling Subsystem Integration & Test

1) Test Objectives

- Primary

  Verify the Ammonia Handling Subsystem meets the requirements of the TBS document(s).

- Secondary

a. TBS

b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Condensers	Support equipment	
2	Evaporators	Support equipment	
3	Interconnect piping	UUT	
4	Manifolds	UUT	
5	Ammonia Supply/Storage	UUT	
6	Ammonia Pumps	UUT	
7	Ammonia Demister	UUT	
8	Instrumentation	Test equipment	
9	DAS	Test equipment	
10	Warm Water Supply	Test equipment	
11	Cold Water Supply	Test equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Ammonia Handling Subsystem Integration & Test Plan		
Ammonia Handling Subsystem Integration & Test Procedures		
Ammonia Handling Subsystem Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.7 Power Cycle (Remora) Fluid Handling Subsystems Integration & Test

1) Test Objectives

- Primary

  Verify the Remora Integrated Fluid Handling Subsystem meets the requirements of the TBS document(s).

- Secondary

a. TBS

b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Condenser and CW Handling Subsystem		
2	Evaporator and WW Handling Subsystem		
3	Ammonia Handling Subsystem		
4	Turbine representative fixture	Test Equipment	
5	DAS		
6	Instrumentation		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Remora Integrated Fluid Handling Subsystem Integration & Test Plan		
Remora Integrated Fluid Handling Subsystem Integration & Test Procedures		
Remora Integrated Fluid Handling Subsystem Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.8 Power Cycle (Remora) Hull (Truss Spar) Subsystem Integration & Test

1) Test Objectives

- Primary

  Verify the Remora Hull Subsystem meets the requirements of the TBS document(s).

- Secondary

a.TBS

b.TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Complete Hull (Hard Tank, Soft Tank, Trusses, braces, foundations/mountings, plates, decks)	Unit Under Test	1
2	Prototype/representative Evaporators	Fit checking, weight & CG	AR
3	Prototype/representative Evaporator plumbing & pumps	Fit checking, weight & CG	AR
4	Prototype/representative Condensers	Fit checking, weight & CG	AR
5	Prototype/representative Condenser plumbing & pumps	Fit checking, weight & CG	AR
6	Prototype/representative Ammonia plumbing & pumps	Fit checking, weight & CG	AR
7	Prototype/representative Warm Water Storage tank	Fit checking, weight & CG	1
8	Crane	Lifting/Handling	1/2
9	Lifting Fixture(s)	Lifting	1
10	Towing Fixtures	Towing	1
11	Data Acquisition System	Test Equipment	1
12	Monitoring & Measurement Instruments	Test Equipment	AR

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Remora Hull Subsystem Integration & Test Plan		
Remora Hull Subsystem Integration & Test Procedures		
Remora Hull Subsystem Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.9 Electrical Generation Turbine-Generator Subsystem Integration & Test

1) Test Objectives

- Primary

  Verify the Turbine-Generator Subsystem meets the requirements of the TBS document(s).

- Secondary

a. TBS

b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Turbine-Generator	Unit Under Test	
2	Turbine plumbing or equivalent	Support Equipment	
3	Generator Cooling		
4	Generator Field Exciter		
5	DAS	Test Equipment	
6	Instrumentation	Test Equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Turbine-Generator Subsystem Integration & Test Plan		
Turbine-Generator Subsystem Integration & Test Procedures		
Turbine-Generator Subsystem Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.10 CWP Connection Qualification Test

1) Test Objectives

- Primary

  Verify the CWP Connection Subsystem meets the requirements of the TBS document(s).

- Secondary

a. TBS

b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	CWP section	Support equipment	
2	CWP termination	Support equipment	
3	CWP to Platform interface	Support equipment	
4	CWP connection	UUT	
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.

DOCUMENT	RESPONSIBILITY	CDRL NO.
CWP Connection Qualification Test Plan		
CWP Connection Qualification Test Procedures		
CWP Connection Qualification Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.11 CWP Termination Qualification Test

1) Test Objectives

- Primary

  Verify the CWP Termination Subsystem meets the requirements of the TBS document(s).

- Secondary

a. TBS

b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
2	CWP connection	Support equipment	
1	CWP section	Support equipment	
2	CWP termination	UUT	
3	CWP to Platform interface	Support equipment	
4	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
CWP Termination Connection Test Plan		
CWP Termination Connection Test Procedures		
CWP Termination Connection Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.12 CWP Subsystem Qualification Test

1) Test Objectives

- Primary

  Verify the CWP Termination Subsystem meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	CWP section	UUT	
2	CWP Termination	Support equipment	
3	CWP to Platform Interface	Support equipment	
4	CWP connection	Support equipment	
5	Guide Simulator	Support equipment	
6	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
CWP Subsystem Qualification Test Plan		
CWP Subsystem Qualification Test Procedures		
CWP Subsystem Qualification Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.13 CWP Anti-biofouling Qualification Test

1) Test Objectives

- Primary

  Verify the CWP Anti-biofouling assembly/system meets the requirements of the TBS document(s).

- Secondary

  a.TBS

  b.TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	CWP test section	Support equipment	
2	Anti-biofouling system	UUT	
3	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
CWP Anti-Biofouling Integration & Test Plan		
CWP Anti-Biofouling Integration & Test Procedures		
CWP Anti-Biofouling Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.14 Evaporator Anti-biofouling & Corrosion Tests

1) Test Objectives

- Primary

  Verify the Evaporator Anti-biofouling and corrosion component/assembly meets the requirements of the TBS document(s).

- Secondary

a. TBS.

b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Warm Water subsystem • Evaporator components • Piping, ducting & valves • Pumps	Support equipment	
2	WW Anti-biofouling & corrosion assembly/equipment	UUT	
3	Environmental DAS	Test equipment	
4	Event DAS	Test equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Evaporator Anti-Biofouling and Corrosion Test Plan		
Evaporator Anti-Biofouling and Corrosion Test Procedures		
Evaporator Anti-Biofouling and Corrosion Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.15 Evaporator Acceptance Test

1) Test Objectives

- Primary

  Verify the Evaporator Anti-biofouling component/assembly meets the requirements of the TBS document(s).

- Secondary

a. TBS.

b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Warm Water subsystem • Evaporator components • Piping, ducting & valves • Pumps	UUT/ Support equipment	
2	WW Anti-biofouling assembly/equipment	UUT	
3	Environmental DAS	Test Equipment	
4	Event DAS	Test Equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Evaporator Anti-Biofouling and Corrosion Acceptance Test Plan		
Evaporator Anti-Biofouling and Corrosion Acceptance Test Procedures		
Evaporator Anti-Biofouling and Corrosion Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.16 Condenser Anti-biofouling & Corrosion Tests

1) Test Objectives

- Primary

  Verify the Condenser Anti-biofouling and Corrosion control components/assembly meets the requirements of the TBS document(s).

- Secondary

a. TBS.

b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Cold Water subsystem • Condenser components • Piping, ducting & valves • Pumps	UUT/ Support equipment	
2	CW Anti-biofouling assembly/equipment	UUT	
3	Environmental DAS	Test Equipment	
4	Event DAS	Test Equipment	
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Condenser Anti-Biofouling & Corrosion Test Plan		
Condenser Anti-Biofouling & Corrosion Test Procedures		
Condenser Anti-Biofouling & Corrosion Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.17 Condenser Acceptance Test

1) Test Objectives

- Primary

  Verify the Condenser components/assembly meets the requirements of the TBS document(s).

- Secondary

a. TBS.

b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Cold Water subsystem • Condenser components • Piping, ducting & valves • Pumps	UUT	
2	CW Anti-biofouling assembly/equipment	Support equipment	
3	Environmental DAS	Test Equipment	
4	Event DAS	Test Equipment	
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Condenser Acceptance Test Plan		
Condenser Acceptance Test Procedures		
Condenser Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.18 Warm Water Subsystem Integration & Test

1) Test Objectives

- Primary

  Verify the Warm Water subsystem meets the requirements of the TBS document(s).

- Secondary

a. TBS.

b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Warm Water subsystem • Evaporator components • Piping, ducting & valves • Pumps	UUT	
2	WW Anti-biofouling assembly/equipment	UUT	
3	Environmental DAS	Test Equipment	
4	Event DAS	Test Equipment	
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Remora Warm Water Subsystem Integration & Test Plan		
Remora Warm Water Subsystem Integration & Test Procedures		
Remora Warm Water Subsystem Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.19 Cold Water Subsystem Integration & Test

1) Test Objectives

- Primary

  Verify the cold water subsystem meets the requirements of the TBS document(s).

- Secondary

a. TBS.

b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Cold Water subsystem • Condenser components • Piping, ducting & valves • Pumps	UUT	
2	CW Anti-biofouling assembly/equipment	UUT	
3	Environmental DAS	Test Equipment	
4	Event DAS	Test Equipment	
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Remora Cold Water Subsystem Integration & Test Plan		
Remora Cold Water Subsystem Integration & Test Procedures		
Remora Cold Water Subsystem Integration & Test		

Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.20 Working Fluid (Ammonia) Subsystem Acceptance Tests

1) Test Objectives

- Primary

  Verify the ammonia (working fluid) subsystem meets the requirements of the TBS document(s).

- Secondary

a. TBS.

b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Ammonia subsystem components • Storage components • Demister • Piping, ducting & valves • Pumps	UUT	
2	Ammonia Anti-corrosion assembly/equipment	UUT	
3	Environmental DAS	Test Equipment	
4	Event DAS	Test Equipment	
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Remora Ammonia Subsystem Acceptance Test Plan		
Remora Ammonia Subsystem Acceptance Test Procedures		
Remora Ammonia Subsystem Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.21 Warm Water Subsystem Acceptance Tests

1) Test Objectives

- Primary

  Verify the warm water subsystem meets the requirements of the TBS document(s).

- Secondary

a. TBS.

b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Warm Water subsystem • Evaporator components • Piping, ducting & valves • Pumps	UUT	
2	WW Anti-biofouling assembly/equipment	UUT	
3	Environmental DAS	Test Equipment	
4	Event DAS	Test Equipment	
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Remora WW Subsystem Acceptance Test Plan		
Remora WW Subsystem Acceptance Test Procedures		
Remora WW Subsystem Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.22 Cold Water Subsystem Acceptance Tests

1) Test Objectives

- Primary

  Verify the cold water subsystem meets the requirements of the TBS document(s).

- Secondary

a. TBS.

b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Cold Water subsystem • Condenser components • Piping, ducting & valves • Pumps	UUT	
2	CW Anti-biofouling assembly/equipment	UUT	
3	Environmental DAS	Test Equipment	
4	Event DAS	Test Equipment	
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Remora CW Subsystem Acceptance Test Plan		
Remora CW Subsystem Acceptance Test Procedures		

DOCUMENT	RESPONSIBILITY	CDRL NO.
Remora CW Subsystem Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.23 Working Fluid (Ammonia) Handling Subsystem I&C Integration & Test

1) Test Objectives

- Primary

  Verify the Remora Ammonia Handling subsystem I&C meets the requirements of the TBS document(s).

- Secondary

a. TBS.

b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Ammonia Handling Subsystem I&C components		
2	II&C Computers, Consoles & Displays	Support equipment	
3	Event DAS	Test equipment	
4	Instrumentation	Test equipment	
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Ammonia Handling Subsystem I&C Integration & Test Plan		
Ammonia Handling Subsystem I&C Integration & Test Procedures		
Ammonia Handling Subsystem I&C Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.24 Warm Water Handling Subsystem I&C Integration & Test

1) Test Objectives

- Primary

  Verify the Remora Warm Water Handling subsystem I&C meets the requirements of the TBS document(s).

- Secondary

a. TBS.

b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Warm Water Handling subsystem I&C components	UUT	
2	II&C Computers, Consoles & Displays	Support equipment	
3	Event DAS	Test equipment	
4	Instrumentation	Test equipment	
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Warm Water Handling subsystem I&C Integration & Test Plan		
Warm Water Handling subsystem I&C Integration & Test Procedures		
Warm Water Handling subsystem I&C Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.25 Cold Water Handling Subsystem I&C Integration & Test

1) Test Objectives

- Primary

  Verify the Remora Cold Water Handling Subsystem I&C meets the requirements of the TBS document(s).

- Secondary

a. TBS.

b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Cold Water Handling Subsystem components • Condenser • Piping, ducting & valves • Pumps • Anti-biofouling/corrosion	UUT	
2	Ammonia subsystem simulator	Test equipment	
3	Event DAS	Test equipment	
4	Environment DAS	Test equipment	
5	Instrumentation	Test equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Cold Water Handling Subsystem I&C Integration & Test Plan		
Cold Water Handling Subsystem I&C Integration & Test Procedures		
Cold Water Handling Subsystem I&C Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.26 Power Cycle (Remora) Subsystem I&C Integration & Test

1) Test Objectives

- Primary

  Verify the Power Cycle (Remora) Subsystem I&C meets the requirements of the TBS document(s).

- Secondary

a. TBS.

b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Power Cycle (Remora) Subsystem components		
2	II&C Computers, Consoles & Displays	Support equipment	
3	Event DAS	Test equipment	
4	Instrumentation	Test equipment	
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Power Cycle (Remora) Subsystem I&C Integration & Test Plan		
Power Cycle (Remora) Subsystem I&C Integration & Test Procedures		
Power Cycle (Remora) Subsystem I&C Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

Power Delivery Segment

6.1.27 Power Transmission Cable Subsystem Integration & Test

1) Test Objectives

- Primary

  Verify the Power Transmission Cable Subsystem meets the requirements of the TBS document(s).

- Secondary

a. TBS

b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Subsea cable or equivalent	Unit Under Test	
2	Subsea cable connections/interfaces	Unit Under Test	
3	Land cable or equivalent	Unit Under Test	
4	Land cable connections/interfaces	Unit Under Test	
5	DAS	Test Equipment	
6	Instrumentation	Test Equipment	
7	Electrical Power measurement equipment	Test Equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Power Transmission Cable Subsystem Integration & Test Plan		
Power Transmission Cable Subsystem Integration & Test Procedures		
Power Transmission Cable Subsystem Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.28 Platform Substation Subsystem Integration & Test

1) Test Objectives

- Primary

  Verify the Platform Substation Subsystem meets the requirements of the TBS document(s).

- Secondary

a. TBS

b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Platform Substation components • Switchgear • Transformers • Batteries • SCADA • Power cabling • Control cabling	Unit Under Test	
2	DAS	Test Equipment	
3	Instrumentation	Test Equipment	
4	Electrical Power measurement equipment	Test Equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Platform Substation Subsystem Integration & Test Plan		
Platform Substation Subsystem Integration & Test Procedures		
Platform Substation Subsystem Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.29 On-Shore Substation Subsystem Integration & Test

1) Test Objectives

- Primary

  Verify the On-Shore Substation Subsystem meets the requirements of the TBS document(s).

- Secondary

a. TBS

b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	On-Shore Substation components • Switchgear • Transformers • Batteries • SCADA • Power cabling Control cabling	Unit Under Test	
2	DAS	Test Equipment	
3	Instrumentation	Test Equipment	
4	Electrical Power measurement equipment	Test Equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
On-Shore Substation Subsystem Integration & Test Plan		
On-Shore Substation Subsystem Integration & Test Procedures		
On-Shore Substation Subsystem Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.30 Platform Substation Subsystem Acceptance Test

1) Test Objectives

- Primary

  Verify the Platform Substation subsystem meets the requirements of the TBS document(s).

- Secondary

a. TBS.

b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved
b. Test Procedures completed, reviewed and approved.
c. Lab construction and checkout completed and approved for use
d. FAT completed for each of the components
e. Dry Runs completed
f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Platform Substation components • Switchgear • Transformers • Batteries • SCADA • Power cabling • Control cabling	UUT	
2	Turbine-Generator simulator	Test equipment	
3	Power transmission cable simulator	Test equipment	
4	TBS		
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Platform Substation Subsystem Acceptance Test Plan		
Platform Substation Subsystem Acceptance Test Procedures		
Platform Substation Subsystem Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.31 Power Transmission Cable Acceptance Test

1) Test Objectives

- Primary

  Verify the power transmission cable subsystem meets the requirements of the TBS document(s).

- Secondary

  a. TBS.

  b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Power Transition Land cable	UUT	
2	Power Transition Undersea cable	UUT	
3	Power Transition Shore Landing Vault	UUT	
4	On-shore substation simulator	Test equipment	
5	Platform substation simulator	Test equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Power Transmission Cable subsystem Acceptance Test Plan		
Power Transmission Cable subsystem Acceptance Test Procedures		
Power Transmission Cable subsystem Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.32 On-Shore Substation Acceptance Test

1) Test Objectives

- Primary

  Verify the on-shore substation subsystem meets the requirements of the TBS document(s).

- Secondary

  a. TBS.

  b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	On-Shore Substation components • Switchgear • Transformers • Batteries • SCADA • Power cabling • Control cabling	UUT	
2	Turbine-Generator simulator	Test equipment	
3	Power transmission cable simulator	Test equipment	
4	TBS		
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
On-Shore Substation Subsystem Acceptance Test Plan		
On-Shore Substation Subsystem Acceptance Test Procedures		
On-Shore Substation Subsystem Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.33 Platform Substation Power Cabling Integration & Test

1) Test Objectives

- Primary

  Verify the Platform Substation Power Cabling subsystem meets the requirements of the TBS document(s).

- Secondary

  a. TBS.

  b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Platform Substation Power Cabling subsystem components	UUT	
2	Simulated Platform electrical service components	Test equipment	
3	Simulated Power transmission cabling	Test equipment	
4	TBS		
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Platform Substation Power Cabling subsystem Integration & Test Plan		
Platform Substation Power Cabling subsystem Integration & Test Procedures		
Platform Substation Power Cabling subsystem Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.34 Auxiliary Power (Diesel Generator) Integration & Test

1) Test Objectives

- Primary

  Verify the Platform Auxiliary Power Diesel Generator subsystem meets the requirements of the TBS document(s).

- Secondary

  a. TBS.

  b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Platform Auxiliary Power Diesel Generator	UUT	
2	TBS		
3	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Platform Auxiliary Power Diesel Generator subsystem Integration & Test Plan		
Platform Auxiliary Power Diesel Generator subsystem Integration & Test Procedures		
Platform Auxiliary Power Diesel Generator subsystem Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

II&C Segment

6.1.35 CWP Subsystem I&C Integration & Test

1) Test Objectives

- Primary

  Verify the CWP Anti-biofouling assembly/system meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	CWP test section	Support equipment	
2	CWP I&C components	UUT	
3	Event DAS	Test equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
CWP Subsystem I&C Integration & Test Plan		
CWP Subsystem I&C Integration & Test Procedures		
CWP Subsystem I&C Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.36 Electrical Generation I&C Integration & Test

1) Test Objectives

- Primary

  Verify the Electrical Generation I&C subsystem meets the requirements of the TBS document(s).

- Secondary

  a. TBS.

  b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Turbine-Generator sensors and controls	Support equipment	
2	II&C Electrical Generation Consoles & Displays	UUT	
3	II&C Electrical Generation Software	UUT	
4	Event DAS	Test Equipment	
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Electrical Generation I&C Integration &Test Plan		
Electrical Generation I&C Integration &Test Procedures		
Electrical Generation I&C Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.37 Electrical Generation I&C Acceptance Test

1) Test Objectives

- Primary

  Verify the Electrical Generation I&C subsystem meets the requirements of the TBS document(s).

- Secondary

  a. TBS.

  b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Turbine-Generator sensors and controls	Support equipment	
2	II&C Electrical Generation Consoles & Displays	UUT	
3	II&C Electrical Generation Software	UUT	
4	Event DAS	Test Equipment	
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Electrical Generation I&C Acceptance Test Plan		
Electrical Generation I&C Acceptance Test Procedures		
Electrical Generation I&C Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

II&C Segment

6.1.38 Platform I&C Subsystem Acceptance Test

1) Test Objectives

- Primary

  Verify the Platform I&C subsystem meets the requirements of the TBS document(s).

- Secondary

  a. TBS.

  b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Platform I&C components	UUT	
2	II&C Computers, Consoles & Displays	Support equipment	
3	Event DAS	Test equipment	
4	Instrumentation	Test equipment	
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Platform I&C subsystem Acceptance Test Plan		
Platform I&C subsystem Acceptance Test Procedures		
Platform I&C subsystem Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.39 Safety, Security & Communication I&C Subsystem Acceptance Test

1) Test Objectives

- Primary

  Verify the Platform Safety, Security and Communication I&C subsystem meets the requirements of the TBS document(s).

- Secondary

  a. TBS.

  b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Platform Safety, Security and Communication I&C components	UUT	
2	II&C Computers, Consoles & Displays	Support equipment	
3	Event DAS	Test equipment	
4	Instrumentation	Test equipment	
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Platform Safety, Security and Communication I&C subsystem Test Plan		
Platform Safety, Security and Communication I&C subsystem Test Procedures		
Platform Safety, Security and Communication I&C subsystem Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.40 Power Cycle (Remora) I&C Subsystem Acceptance Test

1) Test Objectives

- Primary

Verify the Power Cycle (Remora) I&C subsystem meets the requirements of the TBS document(s).

- Secondary
  a. TBS.
  b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved
b. Test Procedures completed, reviewed and approved.
c. Lab construction and checkout completed and approved for use
d. FAT completed for each of the components
e. Dry Runs completed
f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Power Cycle (Remora) I&C subsystem components	UUT	
2	II&C Computers, Consoles & Displays	Support equipment	
3	Event DAS	Test equipment	
4	Instrumentation	Test equipment	
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Power Cycle (Remora) I&C subsystem Acceptance Test Plan		
Power Cycle (Remora) I&C subsystem Acceptance Test Procedures		
Power Cycle (Remora) I&C subsystem		

Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.41 CWP I&C Subsystem Acceptance Test

1) Test Objectives

- Primary

  Verify the CWP I&C subsystem meets the requirements of the TBS document(s).

- Secondary

  a. TBS.

  b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	CWP I&C subsystem components	UUT	
2	II&C Computers, Consoles & Displays	Support equipment	
3	Event DAS	Test equipment	
4	Instrumentation	Test equipment	
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
CWP I&C subsystem Acceptance Test Plan		
CWP I&C subsystem Acceptance Test Procedures		
CWP I&C subsystem Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.42 Electrical Generation I&C Subsystem Acceptance Test

1) Test Objectives

- Primary

  Verify the Electrical Generation I&C subsystem meets the requirements of the TBS document(s).

- Secondary

  a. TBS.

  b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Electrical Generation I&C subsystem components	UUT	
2	II&C Computers, Consoles & Displays	Support equipment	
3	Event DAS	Test equipment	
4	Instrumentation	Test equipment	
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Electrical Generation I&C subsystem Acceptance Test Plan		
Electrical Generation I&C subsystem Acceptance Test Procedures		
Electrical Generation I&C subsystem Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.43 Electrical Delivery I&C Subsystem Acceptance Test

1) Test Objectives

- Primary
- Verify the Electrical Delivery I&C Subsystem meets the requirements of the TBS document(s).
- Secondary
  a. TBS.
  b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved
b. Test Procedures completed, reviewed and approved.
c. Lab construction and checkout completed and approved for use
d. FAT completed for each of the components
e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Electrical Delivery I&C Subsystem components	UUT	
2	II&C Computers, Consoles & Displays	Support equipment	
3	Event DAS	Test equipment	
4	Instrumentation	Test equipment	
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Electrical Delivery I&C Subsystem Acceptance Test Plan		
Electrical Delivery I&C Subsystem Acceptance Test Procedures		
Electrical Delivery I&C Subsystem Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.1.44 Environmental Monitoring I&C Subsystem Acceptance Test

1) Test Objectives

- Primary

  Verify the Environmental Monitoring I&C subsystem meets the requirements of the TBS document(s).

- Secondary

  a. TBS.

  b. TBS.

2) Test Description

These tests consist of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the TBD Test Facility in TBD during TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Environmental Monitoring I&C Subsystem components	UUT	
2	II&C Computers, Consoles & Displays	Support equipment	
3	Event DAS	Test equipment	
4	Instrumentation	Test equipment	
5	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Environmental Monitoring I&C Subsystem Acceptance Test Plan		
Environmental Monitoring I&C Subsystem Acceptance Test Procedures		
Environmental Monitoring I&C Subsystem Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.2 Subsystem Software Integration and Verification

Power Delivery Segment

6.2.1 Platform Substation Subsystem Software Integration & Test

1) Test Objectives

- Primary

  Verify the Platform Substation Subsystem Software meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Platform Substation Monitor/Control Software	Unit Under Test	
2	Platform Substation Host Computer or equivalent	Support Equipment	
3	Platform Substation representative components	Support Equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Platform Substation Subsystem Software Integration & Test Plan		
Platform Substation Subsystem Software Integration & Test Procedures		
Platform Substation Subsystem Software Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

6.2.2 On-Shore Substation Subsystem Software Integration & Test

1) Test Objectives

- Primary

  Verify the On-Shore Substation Subsystem software meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	On-shore Substation Monitor/Control Software	Unit Under Test	
2	On-shore Substation Host Computer or equivalent	Support Equipment	
3	On-shore Substation representative components	Support Equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
On-Shore Substation Subsystem Software Integration & Test Plan		
On-Shore Substation Subsystem Software Integration & Test Procedures		
On-Shore Substation Subsystem Software Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

7 ELEMENT INTEGRATION AND VERIFICATION PLAN

The purpose of this Element Integration Test Plan is to document the integration and test of items and elements to build the specified high-level Segment. Informal testing will occur at each level of integration. The element integration and test phase culminates with a high-level element that is ready for formal qualification testing.

7.1 Element Hardware Integration and Verification

Platform Segment

7.1.1 Platform Structure Element Integration & Test

1) Test Objectives

- Primary

  Verify the Platform Structure (Hull & Topsides) Elements meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Complete Platform (Topsides & Hull Structures)	Unit Under Test	
2	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Platform Structure (Hull & Topsides) Elements Integration & Test Plan		
Platform Structure (Hull & Topsides) Elements Integration & Test Procedures		
Platform Structure (Hull & Topsides) Elements Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

7.1.2 Platform Station keeping Element Integration & Test (At Sea)

1) Test Objectives

- Primary

  Verify the Platform Station keeping Element meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Tensioning	Unit Under Test	
2	Tension Members	Unit Under Test	
3	Seafloor Anchors	Unit Under Test	
4	Platform representative fixture	Support Equipment	
5	Seafloor representative fixture	Support Equipment	
6	Load Cell	Test Equipment	
7	Tension supplying equipment	Test Equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Platform Station keeping Element Integration & Test Plan		
Platform Station keeping Element Integration & Test Procedures		
Platform Station keeping Element Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

7.1.3 Platform Electric Plant Element Integration & Test

1) Test Objectives

- Primary

  Verify the Platform Electric Plant Element meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Platform Electric Plant Components	Unit Under Test	
2	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Platform Electric Plant Element Integration & Test Plan		
Platform Electric Plant Element Integration & Test Procedures		
Platform Electric Plant Element Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

7.1.4 Platform Communications and Control Element Integration & Test

1) Test Objectives

- Primary

  Verify the Platform Communications and Control Element meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Communications and Control components	Unit Under Test	
2	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Platform Communications and Control Element Integration & Test Plan		
Platform Communications and Control Element Integration & Test Procedures		
Platform Communications and Control Element Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

7.1.5 Platform Auxiliary Systems Element Integration & Test

1) Test Objectives

- Primary

Verify the Platform Auxiliary Systems Element meets the requirements of the TBS document(s).

- Secondary
  a. TBS
  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved
b. Test Procedures completed, reviewed and approved.
c. Lab/facility construction and checkout completed and approved for use
d. FAT completed for each of the components
e. Dry Runs completed
f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Auxiliary System Components	Unit Under Test	
2	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Platform Auxiliary Systems Element Integration & Test Plan		
Platform Auxiliary Systems Element Integration & Test Procedures		
Platform Auxiliary Systems Element Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

7.1.6 Platform Outfit & Furnishings Element Integration & Test

1) Test Objectives

- Primary

  Verify the Platform Outfit and Furnishing Element meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Outfit & Furnishing Components	Unit Under Test	
2	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Platform Outfit and Furnishing Element Integration & Test Plan		

Platform Outfit and Furnishing Element Integration & Test Procedures		
Platform Outfit and Furnishing Element Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

Power Geneartion Segment

7.1.7 Power Cycle (Remora) Element Integration & Test

1) Test Objectives

- Primary

  Verify the Remora (Power Cycle) Element meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Working Fluid/Ammonia System	UUT	
2	Cold Water System	UUT	
3	Warm Water System	UUT	
4	Working Fluid Supply	Support equipment	
5	Warm Water Supply	Support equipment	
6	Cold Water Supply	Support equipment	
7	Instrumentation	Test equipment	
8	Event Data Acquisition System	Test equipment	
9	Environmental Data Acquisition System	Test equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Remora (Power Cycle) Element Integration & Test Plan		
Remora (Power Cycle) Element Integration & Test Procedures		
Remora (Power Cycle) Element Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

7.1.8 Electrical Generation Element Acceptance Test

1) Test Objectives

- Primary

  Verify the Electrical Generation Element meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Turbine-Generator	Unit Under Test	
2	Generator Cooling	Unit Under Test	
3	Electrical cabling	Unit Under Test	
4	Remora Interface Piping & Simulation	Support equipment	
5	Filed Exciter	Support equipment	
6	Facility Electrical Power	Support equipment	
7	Instrumentation	Test equipment	
8	Event Data Acquisition System	Test equipment	
9	Environmental Data Acquisition System	Test equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Electrical Generation Element Acceptance Test Plan		
Electrical Generation Element Acceptance Test Procedures		
Electrical Generation Element Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

Power Delivery Segment

7.1.9 Electrical Delivery Element Integration & Test (Quay-Side)

1) Test Objectives

- Primary

  Verify the Electrical Delivery Element meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Transmission Cable simulator?	Unit Under Test	
2	Platform Substation	Unit Under Test	
3	On-Shore Substation	Unit Under Test	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Electrical Delivery Element Integration & Test Plan		
Electrical Delivery Element Integration & Test Procedures		

Electrical Delivery Element Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

II&C Segment

7.1.10 Integrated Instrumentation & Control (II&C) Platform Management Element Integration & Test

1) Test Objectives

- Primary

  Verify the II&C Platform Management Element meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Platform Management Subsystem Components	Unit Under Test	
2	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
II&C Platform Management Element Integration & Test Plan		
II&C Platform Management Element Integration & Test Procedures		
II&C Platform Management Element Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

7.1.11 II&C Power Cycle Management Element Integration & Test

1) Test Objectives

- Primary

  Verify the II&C Power Cycle Management Element meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Power Cycle Control Subsystem Components	Unit Under Test	
2	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
II&C Power Cycle Management Element Integration & Test Plan		
II&C Power Cycle Management Element Integration & Test Procedures		
II&C Power Cycle Management Element Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

7.1.12 II&C Environmental Monitoring Management Element Integration & Test

1) Test Objectives

- Primary

  Verify the II&C Environmental Monitoring Management Element meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the II&C Environmental Monitoring TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Env Monitoring Subsystem Components	Unit Under Test	
2	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
II&C Environmental Monitoring Management Element Integration & Test Plan		
II&C Environmental Monitoring Management Element Integration & Test Procedures		
II&C Environmental Monitoring Management Element Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

7.1.13 II&C On-Shore Substation Element Integration & Test

1) Test Objectives

- Primary

  Verify the II&C On-Shore Substation Element meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the II&C On-Shore Substation TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Shore Station Element I&C Components	Unit Under Test	
2	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
II&C On-Shore Substation Element Integration & Test Plan		
II&C On-Shore Substation Element Integration & Test Procedures		
II&C On-Shore Substation Element Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

7.1.14 II&C Platform Substation Element Acceptance Test

1) Test Objectives

- Primary

  Verify the II&C Platform Substation Element meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Platform Substation I&C Components	Unit Under Test	
2	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
II&C Platform Substation Element Acceptance Test Plan		
II&C Platform Substation Element Acceptance Test Procedures		
II&C Platform Substation Element Acceptance Test Report		

8) Success Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

7.1.15 II&C Power Cable Element Acceptance Test

1) Test Objectives

- Primary

  Verify the II&C Power Cable Element meets the requirements of the TBS document(s).

- Secondary

  a. TBS

b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the II&C Power Cable TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Power Cable I&C Components	Unit Under Test	
2	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
II&C Power Cable Element Acceptance Test Plan		
II&C Power Cable Element Acceptance Test Procedures		
II&C Power Cable Element Acceptance Test Report		

8) Success Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

7.1.16 II&C Power Cycle Element Acceptance Test

1) Test Objectives

- Primary

  Verify the II&C Power Cycle Element meets the requirements of the TBS document(s).

- Secondary
  a. TBS
  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved
b. Test Procedures completed, reviewed and approved.
c. Lab/facility construction and checkout completed and approved for use
d. FAT completed for each of the components
e. Dry Runs completed
f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Power Cycle I&C Components	Unit Under Test	
2	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
II&C Power Cycle Element Acceptance Test Plan		
II&C Power Cycle Element Acceptance Test Procedures		
II&C Power Cycle Element Acceptance Test Report		

8) Success Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

7.2 Element Software Integration and Verification

II&C Segment

7.2.1 Integrated Instrumentation & Control (II&C) Platform Management Software Integration & Test

1) Test Objectives

- Primary

  Verify the II&C Platform Management Software meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Platform Management I&C Software	Unit Under Test	
2	Platform Management I&C Software Host Computer	Support Equipment	
3	Platform Management I&C Software Display	Support Equipment	
4	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
II&C Platform Management Software Integration & Test Plan		
II&C Platform Management Software Integration & Test Procedures		
II&C Platform Management Software Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

7.2.2 II&C Power Cycle Management Software Integration & Test

1) Test Objectives

- Primary

  Verify the II&C Power Cycle Management Software meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the Power Cycle Management Software TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Power Cycle I&C Software	Unit Under Test	
2	Power Cycle I&C Software Host Computer	Support Equipment	
3	Power Cycle I&C Consoles & Display	Support Equipment	
4	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
II&C Power Cycle Management Software Integration & Test Plan		
II&C Power Cycle Management Software Integration & Test Procedures		
II&C Power Cycle Management Software Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

7.2.3 II&C Environmental Monitoring Management Software Integration & Test

1) Test Objectives

- Primary

  Verify the II&C Environmental Monitoring Management Software meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the Environmental Monitoring Management Software TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Env Monitor I&C Software	Unit Under Test	
2	Env Monitor I&C Software Host Computer	Support Equipment	
3	Env Monitor I&C Software Display	Support Equipment	
4	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
II&C Environmental Monitoring Management Software Integration & Test Plan		
II&C Environmental Monitoring Management Software Integration & Test Procedures		
II&C Environmental Monitoring Management Software Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

8 SEGMENT INTEGRATION AND VERIFICATION PLAN

The purpose of this Segment Integration and Test Plan is to document the integration and test of items and elements to build the specified next higher-level system. Informal testing will occur at each level of integration. The segment integration and test phase culminates with segments that are ready for formal qualification and acceptance testing.

8.1 Segment Hardware Integration and Verification

8.1.1 Platform Segment Integration & Test (Quay-Side)

1) Test Objectives

- Primary

  Verify the Platform Segment meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the Platform Segment Integration & Test TRR

4) Test Schedule & Location

This test will be conducted Quay-side in Hawaii at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Platform Segment w/o Station keeping Elements	UUT	
2	TBS		
3	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Platform Segment Integration & Test Plan		
Platform Segment Integration & Test Procedures		
Platform Segment Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

8.1.2 Power Generation Segment Integration & Test (LBTS)

1) Test Objectives

- Primary

  Verify the Power Generation Segment meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Power Cycle Element (Remora)	Unit Under Test	
2	Turbine-Generator Element	Unit Under Test	
3	CWP	Support Equipment	
4	Platform	Support Equipment	
5	Dummy Load	Test Equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Power Generation Segment Integration & Test Plan		
Power Generation Segment Integration & Test Procedures		
Power Generation Segment Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

8.1.3 Power Delivery Segment Integration & Test (At Sea)

1) Test Objectives

- Primary

  Verify the Power Delivery Segment meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

- Completion of all lower level testing:
  - Transmission Cable Installation Acceptance Test
  - Platform Substation Installation Acceptance Test
  - On-Shore Substation Installation Acceptance Test
- Release of approved Test Procedures
- Completion of the TRR

4) Test Schedule & Location

This test will be conducted At Sea at the Pilot Plant deployment site in Hawaii.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Transmission Cable	Unit Under Test	
2	Platform Substation	Unit Under Test	
3	On-Shore Substation	Unit Under Test	
4	Dummy Load	Test Equipment	
5	Power Monitoring & Measurement Equipment	Test Equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Power Delivery Segment Integration & Test Plan		
Power Delivery Segment Integration & Test Procedures		
Power Delivery Segment Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

8.1.4 Integrated Instrumentation & Control Segment Integration & Test (Quay-Side)

1) Test Objectives

- Primary

  Verify the Integrated Instrumentation & Control Segment meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved
b. Test Procedures completed, reviewed and approved.
c. Lab/facility construction and checkout completed and approved for use
d. FAT completed for each of the components
e. Dry Runs completed
f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted Quay-side in Hawaii at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Consoles & Computers	Unit Under Test	
2	Displays	Unit Under Test	
3	Interconnect cabling	Unit Under Test	
4	Software	Unit Under Test	
5	Simulated Instrumentation inputs (SW?)	Test Equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Integrated Instrumentation & Control Segment Integration & Test Plan		
Integrated Instrumentation & Control Segment Integration & Test Procedures		
Integrated Instrumentation & Control Segment Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

8.1.5 CWP Fabrication Apparatus Segment Integration & Test (Step 2) (Engineering Test – Quay-side)

1) Test Objectives

- Primary

Verify the CWP Fabrication Apparatus Segment meets the requirements of the TBS document(s).

- Secondary
  a. TBS
  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved
b. Test Procedures completed, reviewed and approved.
c. Lab/facility construction and checkout completed and approved for use
d. FAT completed for each of the components
e. Dry Runs completed
f. Successful completion of the TRR

4) Test Schedule & Location

This test will be performed at a LBTS (Building 132) at LM-SCC in Sunnyvale CA 3rd Quarter 2010

5) Test Configuration

TBS

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Core Assembly Region		
2	Fabric Placement/Dispensing Region		
3	Molding, Resin Infusion & Vacuum Region		
4	Core Planks		
5	Shear Keys		
6	Alignment Fixture		
7	Resin		
8	Fabric		
9	Gripper/Handler or equivalent		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
CWP Fabrication Apparatus Segment Integration & Test Plan		
CWP Fabrication Apparatus Segment Integration & Test Procedures		
CWP Fabrication Apparatus Segment Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

8.1.6 CWP Fabrication Environmental Enclosure Segment Integration & Test (Quay-Side)

1) Test Objectives

- Primary

  Verify the CWP Fabrication Environmental Enclosure Segment meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted Quay-side in Hawaii at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Enclosure Structure		
2	Enclosure Panels		
3	Material Handling Systems		
4	HVAC		
5	Control Systems		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
CWP Fabrication Environmental Enclosure Segment Integration & Test Plan		
CWP Fabrication Environmental Enclosure Segment Integration & Test Procedures		
CWP Fabrication Environmental Enclosure Segment Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

8.1.7 CWP Gripper/Handler Segment Integration & Test (LBTS?)

1) Test Objectives

- Primary

  Verify the CWP Gripper/Handler Segment meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	CWP Gripper Assembly	UUT	
2	CWP Guide Assembly	UUT	
3	Section of CWP	Support equipment	
4	Support Structure	Support equipment	
5	Instrumentation	Test equipment	
6	DAS	Test equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
CWP Gripper/Handler Segment Integration & Test Plan		
CWP Gripper/Handler Segment Integration & Test Procedures		
CWP Gripper/Handler Segment Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

8.1.8 CWP Fabrication System Engineering Integration & Test (Step 3) (At Sea)

1) Test Objectives

- Primary

  Verify the CWP Fabrication System meets the requirements of the TBS document(s).

- Secondary

  a. TBS

b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted At Sea at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	CWP Gripper/Handler System	Support equipment	
2	CWP Fab Apparatus	UUT	
3	CWP Env Enclosure	UUT	
4	Core Planks	Fab Material	
5	Shear Keys	Fab Material	
6	Alignment Fixture	Support Equipment	
7	Resin	Fab Material	
8	Fabric	Fab Material	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
CWP Fabrication System At Sea Integration & Test Plan		
CWP Fabrication System At Sea Integration & Test Procedures		
CWP Fabrication System At Sea Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

8.1.9 CWP Fabrication System Environmental Enclosure Segment Acceptance Test (Quay-Side or At Sea?)

1) Test Objectives

- Primary

  Verify the CWP Fabrication System Environmental Enclosure Segment meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	CWP Gripper/Handler System	Support equipment	
2	CWP Fab Apparatus	UUT	
3	CWP Env Enclosure	UUT	
4	Core Planks	Fab Material	
5	Shear Keys	Fab Material	
6	Alignment Fixture	Support Equipment	
7	Resin	Fab Material	
8	Fabric	Fab Material	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
CWP Fabrication System Environmental Enclosure Segment Acceptance Test Plan		
CWP Fabrication System Environmental Enclosure Segment Acceptance Test Procedures		
CWP Fabrication System Environmental Enclosure Segment Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

8.1.10 CWP Gripper/Handler System Acceptance Test

1) Test Objectives

- Primary

  Verify the CWP Gripper/Handler Segment meets the requirements of the TBS document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	CWP Gripper/Handler System	UUT	
2	Support Structure	UUT	
3	CWP Section	Support Equipment	
4	Instrumentation	Test equipment	
5	DAS	Test equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
CWP Gripper/Handler Segment Acceptance Test Plan		
CWP Gripper/Handler Segment Acceptance Test Procedures		
CWP Gripper/Handler Segment Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

8.2 Segment Software Integration and Verification

The software integration and test environment, facilities, platform, software/hardware, integration and functional code, performance monitoring tools, test database, test hardware, and test software necessary to perform the software element integration and test activity are TBD.

The software integration plans and methods including integration sequence and criteria for readiness and successful integration are TBD.

How software test procedures are documented, how anomalies are documented and tracked to resolution, and how results are documented and reviewed are TBD.

8.2.1 Integrated Instrumentation & Control (II&C) Segment Software Integration & Test

1) Test Objectives

- Primary

  Verify the II&C Segment software program(s) meets the requirements of the TBS Specification document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	II&C Consoles and Displays	Support equipment	
2	II&C Software	UUT	
3	II&C Host computer	Support equipment	
4	Event DAS	Test equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
II&C Segment software Integration & Test Plan		
II&C Segment software Integration & Test Procedures		
II&C Segment software Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

8.2.2 Integrated Instrumentation & Control Segment Software Acceptance Test

1) Test Objectives

- Primary

  Verify the II&C Segment software meets the requirements of the II&C Segment Specification document and the II&C CONOPS/Operational Scenario document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	II&C Consoles and Displays	Support equipment	
2	II&C Software	UUT	
3	II&C Host computer	Support equipment	
4	Event DAS	Test equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
II&C Segment Software Acceptance Test Plan		
II&C Segment Software Acceptance Test Procedures		
II&C Segment Software Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

8.3 Higher-Level Element/Segment Acceptance/Integration and Verification Plan

8.3.1 Platform Segment Acceptance Test (At Sea)

1) Test Objectives

- Primary

  Verify the Platform Segment meets the requirements of the TBS Specification document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted At Sea at the Pilot Plant deployment site in Hawaii.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Complete Platform Segment (Topsides and Hull)	UUT	
2	TBS		
3	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Platform Segment Acceptance Test Plan		
Platform Segment Acceptance Test Procedures		
Platform Segment Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

8.3.2 CWP Fabrication System Integration & Test (Quay-Side)

1) Test Objectives

- Primary

  Verify the CWP Fabrication System meets the requirements of the TBS Specification document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at Quay-side in Hawaii at TBS.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	CWP Fab Apparatus & Support Structure	UUT	
2	CWP Fab Environmental Enclosure	UUT	
3	Gripper/Handler System	UUT	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
CWP Fabrication System Integration & Test Plan		
CWP Fabrication System Integration & Test Procedures		
CWP Fabrication System Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

8.3.3 CWP Fabrication System Acceptance Test (At-Sea)

1) Test Objectives

- Primary

Verify the CWP Fabrication System meets the requirements of the CWP Fab System Specification and the CWP Installation CONOPS/Operational Scenario document(s).

- Secondary
  a. TBS
  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved
b. Test Procedures completed, reviewed and approved.
c. Lab/facility construction and checkout completed and approved for use
d. FAT completed for each of the components
e. Dry Runs completed
f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted At Sea at the Pilot plant deployment site in Hawaii.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Complete CWP Fabrication System: • Fab Apparatus & Support Structure Segment • Environmental Enclosure Segment • Gripper/Handler System Segment	UUT	
2	Core Planks	Material/support equipment	
3	Shear Keys	Material/support equipment	
4	Fabric Rolls	Material/support equipment	
5	Resin & Catalyst	Material/support equipment	
6	Core Assembly Alignment Fixtures	Support equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
CWP Fabrication System Acceptance Test Plan		
CWP Fabrication System Acceptance Test Procedures		
CWP Fabrication System Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

8.3.4 Power Generation Segment Integration & Test (Quay-Side)

1) Test Objectives

- Primary

  Verify the Power Generation Segment (Remora& Turbine-Generator) meets the selected/feasible portions of the requirements of the Power Cycle Element Specification, the Electrical Generation Element Specification, and the Power Cycle Element to Electrical Generation Element Interface Specification.

- Secondary

  a. TBS

  b. TBS

2) Test Description

The CWP will not be a part of this test. The power generation System will be tested with the Remora in the horizontal position and temporary connections made to the Turbine-Generator, fluid supplies, and electrical and signal cables.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted Quay-side in Hawaii at TBS.

5) Test Configuration

The Remora will be floated adjacent to the OTEC Platform and will be connected to the Turbine-Generator, Warm Water source, Cold Water source, Ammonia Source, and electrical service via

temporary (test only) means. Configuration limitation will dictate the number and type of tests that are feasible/desirable.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Remora Element		
2	Turbine-Generator Set		
3	Cold Water Supply		
4	Warm Water Supply		
5	Working Fluid (Ammonia) Supply		
6	Electrical Service		
7	Electrical cabling	Test equipment	
8	Ammonia Piping and ducting	Test equipment	
9	Seawater Piping and ducting	Test equipment	
10	Instrumentation	Test equipment	
11	DAS	Test equipment	
12	II&C System (partial)	Test equipment	
13	II&C interface cabling	Test equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Power Generation Segment Integration & Test Plan		
Power Generation Segment Integration & Test Procedures		
Power Generation Segment Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

8.3.5 Power Generation Segment Acceptance Test (Quay-Side)

1) Test Objectives

- Primary

  Verify the Power Generation Segment (Remora& Turbine-Generator) meets the selected/feasible portions of the requirements of the Power Cycle Element Specification, the Electrical Generation Element Specification, and the Power Cycle Element to Electrical

Generation Element Interface Specification. Additionally, requirements and operation scenarios from the CONOPS, and customer expectations will be validated.

- Secondary
  a. TBS
  b. TBS

2) Test Description

The CWP will not be a part of this test. The power generation System will be tested with the Remora in the horizontal position and temporary connections made to the Turbine-Generator, fluid supplies, and electrical and signal cables.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved
b. Test Procedures completed, reviewed and approved.
c. Lab/facility construction and checkout completed and approved for use
d. FAT completed for each of the components
e. Dry Runs completed
f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted Quay-Side in Hawaii in TBD.

5) Test Configuration

The Remora will be floated adjacent to the OTEC Platform and will be connected to the Turbine-Generator, Warm Water source, Cold Water source, Ammonia Source, and electrical service via temporary (test only) means. Configuration limitation will dictate the number and type of tests that are feasible/desirable.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Remora	UUT	
2	Turbine-Generator Set	Support equipment	
3	Cold Water Supply	Support equipment	
4	Warm Water Supply	Support equipment	
5	Working Fluid (Ammonia) Supply	Support equipment	
6	Electrical Service	Support equipment	
7	Electrical cabling	Test equipment	
8	Ammonia Piping and ducting	Test equipment	
9	Seawater Piping and ducting	Test equipment	
10	Instrumentation	Test equipment	
11	DAS	Test equipment	
12	II&C System (partial)	Test equipment	
13	II&C interface cabling	Test equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Power Generation Segment Acceptance Test Plan		
Power Generation Segment Acceptance Test Procedures		
Power Generation Segment Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

8.3.6 Power Delivery Segment Acceptance Test (At Sea)

1) Test Objectives

- Primary

  Verify the Power Delivery Segment meets the requirements of the Power Delivery Segment Specification and the CONOPS/Operational Scenario document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted At Sea at the Pilot Plant deployment site in Hawaii.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Power Transmission Cable • Land Cable • Undersea Cable • Shore landing vault	UUT	
2	Platform Substation	UUT	
3	Onshore Substation	UUT	
4	Turbine-Generator connection/junction box	Support equipment	
5	Instrumentation	Test equipment	
6	Event DAS	Test equipment	
7	Environment DAS	Test equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
Power Delivery Segment Acceptance Test Plan		
Power Delivery Segment Acceptance Test Procedures		
Power Delivery Segment Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

8.3.7 Integrated Instrumentation & Control Segment Integration & Test (At Sea)

1) Test Objectives

- Primary

  Verify the Integrated Instrumentation & Control (II&C) Segment meets the requirements of the Integrated Instrumentation & Control Segment Specification document.

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at At Sea at the Pilot Plant deployment site in Hawaii in TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	II&C Consoles & Displays	Unit Under Test	
2	II&C Host Computers	Unit Under Test	
3	II&C Interconnect cabling	Unit Under Test	
4	II&C Software	Unit Under Test	
5	Actual or simulated Instrumentation & control inputs from all other Segments	Test Equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
II&C Segment Integration & Test Plan		
II&C Segment Integration & Test Procedures		
II&C Segment Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

8.3.8 Integrated Instrumentation & Control Segment Acceptance Test (At Sea)

1) Test Objectives

- Primary

  Verify the Integrated Instrumentation & Control (II&C) Segment meets the requirements of the Integrated Instrumentation & Control Segment Specification and CONOPS requirements and operational scenario document(s).

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at At Sea at the Pilot Plant deployment site in Hawaii.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Control Center (MCC) Consoles & Computers	Unit Under Test	
2	Control Center (MCC) Displays & Monitors	Unit Under Test	
3	Interconnect cabling	Unit Under Test	
4	II&C Software	Unit Under Test	
5	Instrumentation inputs from all other Segments	Test Equipment	
6	DAS	Test Equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
II&C Segment Acceptance Test Plan		
II&C Segment Acceptance Test Procedures		
II&C Segment Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

8.4 Regression Test and Retest

Regression and retest guidelines and how they will be applied to item/element verification events are TBD.

9 SYSTEM INTEGRATION, VERIFICATION AND VALIDATION

The purpose of System I,V&V is to ensure that a quality product results from the system solution that embodies the agreed-upon requirements. The effort has traditionally been known as integration and test. The Systems Engineering Process considers three practice elements in this focus area: Integrate System, Verify System Product, and Validate System Product. The practices used to perform System I,V&V are referenced in the program's PMP-NRE.

9.1 System I,V&V Approach

This section summarizes the planned System I,V&V approach to the OTEC Pilot Plant.

9.2 System Integration and Verification

9.2.1 System Environmental Qualification Tests

Environmental verification will be conducted on the OTEC Pilot Plant System components to ensure that the equipment can withstand the environmental and electrical stresses listed in the specifications. These tests will be conducted in accordance with the procedures shown in Table 9.2.1-1.

Table 9.2.1-1 - Environmental Tests Summary

Product	Product #	Serial #	Procedure #	Description
??	*??*	*??*	*??*	Weight
??	*??*	*??*	*??*	Size
??	*??*	*??*	*??*	Parts and Materials
??	*??*	*??*	*??*	Finish
??	*??*	*??*	*??*	Markings and Identification
??	*??*	*??*	*??*	Safety
??	*??*	*??*	*??*	Workmanship
??	*??*	*??*	*??*	Steady State Voltage & Frequency
??	*??*	*??*	*??*	Transient Voltage
??	*??*	*??*	*??*	Transient Frequency
??	*??*	*??*	*??*	Power Interruption
??	*??*	*??*	*??*	Power & Power Factor
??	*??*	*??*	*??*	Leakage Current
??	*??*	*??*	*??*	Vibration
??	*??*	*??*	*??*	Shock
??	*??*	*??*	*??*	Low Temperature
??	*??*	*??*	*??*	High Temperature

Product	Product #	Serial #	Procedure #	Description
??	*??*	*??*	*??*	**Thermal Design**
??	*??*	*??*	*??*	Humidity

9.2.2 Electromagnetic Interference Test

Electromagnetic Interference Tests will be conducted on OTEC Pilot Plant components to ensure the equipment can withstand the requirements set forth in the specifications. Electromagnetic Interference Tests will be conducted in accordance with the procedures shown in Table 9.2.2-1.

Table 9.2.2-1 - EMI/EMC Tests Summary

Product	Product #	Serial #	Procedure #	Description
??	*??*	*??*	*??*	Conducted Emissions, Pwr, up to 15 kHz
				Conducted Emissions, Pwr, .015 to 15 MHz
				Conducted Emissions, Ant Term, 10 kHz to 26 GHz
				Conducted Susceptibility, Pwr Leads, 30 Hz to 50 kHz
				Conducted Suscept, Pwr/Ctl Leads, 30 Hz to 50 kHz
				Inter modulation, 15 kHz to 10 GHz
				Rejection of Undesired Signals, 30 Hz to 20 GHz
				Cross-modulation, 30 Hz to 20 GHz
				Conducted Susceptibility, Spikes, Pwr Leads
				Radiated Emissions, Magnetic Field, 0.03 to 50 kHz
				Radiated Emissions, Electric Field, 14 kHz to 10 GHz
				Radiated Suscept, Magnetic Field, 0.03 to 50 kHz
				Radiated Suscept, Mag Elec Fields, Spikes Pwr Freq.
				Radiated Susceptibility, Elec Field, 14 kHz to 40 GHz

9.2.3 OTEC Pilot Plant Shipyard Integration & Test (LBTS)

1) Test Objectives

- Primary

  Verify the OTEC Pilot Plant meets the requirements of the OTEC Pilot Plant System Specification.

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of integrating and testing the Platform and components and systems that will be installed at the builder's site. This includes TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at the Shipyard/Platform Builder's facility, on land and in the water as applicable.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	Platform Segment		
2	Electrical Generation Element		
3	Integrated Instrumentation & Control Segment		
4	CWP Fabrication interfaces		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
OTEC Pilot Plant Shipyard Integration & Test Plan		

DOCUMENT	RESPONSIBILITY	CDRL NO.
OTEC Pilot Plant Shipyard Integration & Test Procedures		
OTEC Pilot Plant Shipyard Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

9.2.4 OTEC Pilot Plant Quay-Side Integration & Test

1) Test Objectives

- Primary

  Verify the OTEC Pilot Plant meets the requirements of the OTEC Pilot Plant System Specification.

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of integrating and testing the components and systems that will be added at the Quay-site location. This includes Remora horizontal/afloat testing, CWP Fabrication System, and the Platform Substation.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at Quay-Side in Hawaii.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	OTEC Pilot Plant System • Platform Segment • Power Cycle Element • Electrical Generation Element • Integrated Instrumentation & Control Segment		
2	CWP Fabrication System		
3	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
OTEC Pilot Plant Quay-side Integration & Test Plan		
OTEC Pilot Plant Quay-side Integration & Test Procedures		
OTEC Pilot Plant Quay-side Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

9.2.5 OTEC Pilot Plant At Sea Integration & Test

1) Test Objectives

- Primary

  Verify the OTEC Pilot Plant meets the requirements of the OTEC Pilot Plant System Specification.

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of integrating and testing the components and systems that will be added at the deployment-site "at sea" location. This includes CWP Fabrication, Remora, Power Transmission Cabling, On-Shore Substation.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at At Sea at the Pilot Plant deployment site in Hawaii in TBD.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	OTEC Pilot Plant System • Platform Segment • Power Generation Segment • Power Delivery Segment • Integrated Instrumentation & Control Segment	UUT	
2	CWP Fabrication System	Support equipment	
3	Event DAS	Test equipment	
4	Environment DAS	Test equipment	

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
OTEC Pilot Plant At Sea Integration & Test Plan		
OTEC Pilot Plant At Sea Integration & Test Procedures		
OTEC Pilot Plant At Sea Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

9.2.6 OTEC Pilot Plant System Acceptance Test (At-Sea)

1) Test Objectives

- Primary

  Verify the OTEC Pilot Plant System meets the requirements of the OTEC Pilot Plant System Specification, Top-Level Requirements, and CONOPS requirements and operational scenario.

- Secondary
  a. TBS
  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved
b. Test Procedures completed, reviewed and approved.
c. Lab/facility construction and checkout completed and approved for use
d. FAT completed for each of the components
e. Dry Runs completed
f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at At Sea at the Pilot Plant deployment site in Hawaii.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	OTEC Pilot Plant System • Platform Segment • Power Generation Segment • Power Delivery Segment • Integrated Instrumentation & Control Segment		
2	TBS		
3	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
OTEC Pilot Plant System Acceptance Test Plan		
OTEC Pilot Plant System Acceptance Test Procedures		
OTEC Pilot Plant System Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

9.2.7 OTEC Pilot Plant to On-shore Sub-Station Interface Integration & Test (At-Sea)

1) Test Objectives

- Primary

  Verify the OTEC Pilot Plant meets the requirements of the OTEC Pilot Plant System Specification, and Pilot Plant to On-shore Substation Interface Specification.

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Facility construction and checkout completed and approved for use

d. FQT completed for the On-Shore Substation

e. Dry Runs completed

f. Successful completion of the Pilot Plant to On-Shore Substation TRR

4) Test Schedule & Location

This test will be conducted At Sea at the Pilot Plant deployment site in Hawaii.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	OTEC Pilot Plant System		
2	On-Shore Electrical Substation		
3	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.

DOCUMENT	RESPONSIBILITY	CDRL NO.
OTEC Pilot Plant System to On-Shore Substation Integration & Test Plan		
OTEC Pilot Plant System to On-Shore Substation Integration & Test Procedures		
OTEC Pilot Plant System to On-Shore Substation Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

9.2.8 OTEC Pilot Plant to On-shore Sub-Station Interface Acceptance Test (At-Sea)

1) Test Objectives

- Primary

  Verify the OTEC Pilot Plant meets the requirements of the OTEC Pilot Plant System Specification, Pilot Plant to On-shore Substation Interface Specification, and CONOPS Operational Scenarios and requirements.

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted At Sea at the Pilot Plant deployment site in Hawaii.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	OTEC Pilot Plant System		
2	On-Shore Electrical Substation		
3	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
OTEC Pilot Plant to On-Shore Substation Acceptance Test Plan		
OTEC Pilot Plant to On-Shore Substation Acceptance Test Procedures		
OTEC Pilot Plant to On-Shore Substation Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

9.2.9 OTEC Pilot Plant to Grid Interface Integration & Test (At Sea)

1) Test Objectives

- Primary

  Verify the OTEC Pilot Plant System meets the requirements of the OTEC Pilot Plant System Specification, Top-Level Requirements, Pilot Plant to Grid Interface Specification, and the CONOPS requirements and operational scenarios.

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at At Sea at the Pilot Plant deployment site in Hawaii.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	OTEC Pilot Plant System		
2	Local Electrical Grid System		
3	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
OTEC Pilot Plant to Grid Interface Integration & Test Plan		
OTEC Pilot Plant to Grid Interface Integration & Test Procedures		
OTEC Pilot Plant to Grid Interface Integration & Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

9.2.10 OTEC Pilot Plant to Grid Interface Acceptance Test (At Sea)

1) Test Objectives

- Primary

  Verify the OTEC Pilot Plant meets the requirements of the OTEC Pilot Plant System Specification, Top-Level Requirements, Pilot Plant to Grid Interface Specification, and the CONOPS requirements and operational scenarios.

- Secondary

  a. TBS

  b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the TRR

4) Test Schedule & Location

This test will be conducted at At Sea at the Pilot Plant deployment site in Hawaii.

5) Test Configuration

TBS.

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	OTEC Pilot Plant System		
2	Local Electrical Grid System		
3	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
OTEC Pilot Plant to Grid Interface Acceptance Test Plan		
OTEC Pilot Plant to Grid Interface Acceptance Test Procedures		
OTEC Pilot Plant to Grid Interface Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

9.2.11 OTEC Pilot Plant System Final Acceptance Test (At-Sea)

1) Test Objectives

- Primary

  Verify the OTEC Pilot Plant meets the requirements of the OTEC Pilot Plant System Specification, Top-Level Requirements, and CONOPS requirements and operational scenario.

- Secondary

a. TBS

b. TBS

2) Test Description

This test consists of TBS.

3) Prerequisites/Entry Criteria

The following are prerequisites to the start of this test:

a. Test Plan completed, reviewed and approved

b. Test Procedures completed, reviewed and approved.

c. Lab/facility construction and checkout completed and approved for use

d. FAT completed for each of the components

e. Dry Runs completed

f. Successful completion of the Pilot Plant Final System Acceptance TRR

4) Test Schedule & Location

This test will be conducted at At Sea at the Pilot Plant deployment site in Hawaii.

5) Test Configuration

OTEC Pilot Plant System with all Segment, Elements, Subsystem and Components..

6) Test Resources

The following resources are required for this test.

ITEM	DESCRIPTION	FUNCTION	QTY
1	OTEC Pilot Plant System		
2	Local Electrical Grid System		
3	TBS		

7) Test Documentation

The following documents will be compiled as part of this test.

DOCUMENT	RESPONSIBILITY	CDRL NO.
OTEC Pilot Plant System Final Acceptance Test Plan		
OTEC Pilot Plant System Final Acceptance Test Procedures		
OTEC Pilot Plant System Final Acceptance Test Report		

8) Success (Exit) Criteria

For this test event to be considered a success, the objectives and test events specified in the Test Plan and the data specified in the Test Procedures must be collected for each unit under test. Detailed success criteria are specified in the Test Plan.

9.3 System Validation

In addition to validation testing, a validation checklist will be developed and executed to cover those "non-testable" validation requirements specified in the contract.

9.3.1 Supportability Demonstrations

Table 9.3.1-1 summarizes any supportability demonstrations required by or for the customer on the OTEC Pilot Plant project.

Table 9.3.1-1 - Supportability Demonstrations Summary

Product	Product #	Serial #	Procedure #	Demonstration
??	*??*	*??*	*??*	Maintainability
??	*??*	*??*	*??*	Testability
??	*??*	*??*	*??*	BIT/Fault Isolation
??	*??*	*??*	*??*	Manual Maintenance
??	*??*	*??*	*??*	LRU Accessibility
??	*??*	*??*	*??*	Human Factors
??	*??*	*??*	*??*	Reliability
??	*??*	*??*	*??*	Safety

9.3.2 Other Customer Testing

Table 9.3.2-1 summarizes any additional testing required by or for the customer on the OTEC Pilot Plant project.

Table 9.3.2-1 - Other Tests/Audits Summary

Product	Product #	Serial #	Procedure #	Location	Description
??	*??*	*??*	*??*	*??*	Functional Configuration Audit
??	*??*	*??*	*??*	*??*	Physical Configuration Audit
??	*??*	*??*	*??*	*??*	Independent Verification and Validation
??	*??*	*??*	*??*	*??*	Formal Acceptance Testing (Pre-production)

10 FACILITY AND TEST RESOURCE REQUIREMENTS

10.1 System Integration & Verification Facilities and Test Resource Requirements

10.1.1 Facility Requirements

- Components and Subsystems fab and test at vendors/suppliers facilities
- Hx Lab - Manassas
- Remora Build-up space – Hx & Ammonia Systems facility/lab - Makai
- Turbine-Generator Build-up space facility/lab – Manassas? Makai?
- Controls System Build-up and test space – Riv Beach?
- CWP Development testing (LBTS) – Sunnyvale
- CWP Development testing (Quay-side) – on vessel at Shipyard/Dock in CA or HI
- CWP Development (at Sea) - on vessel in HI
- Platform Fab & Test – Shipyard
- Integration Quay-side – Shipyard/Dock in HI

Table 10.1.1-1 below contains the facility requirements needed to support system integration.

Table 10.1.1-1 - System I&V Facility Requirements

Facility Parameter	(Minimum) Requirement
Floor Space	*??*
Power	*??*
Workbenches/Desks	*??*
Heat/AC Load	*??*
LAN Service/Phones	*??*
RF Screening	*??*
Security Level	*??*

Table 10.1.1-2 below contains the facility requirements needed to support system verification.

Table 10.1.1-2 - System I&V Facility Requirements

Facility Parameter	(Minimum) Requirement
Security Level	*??*
Floor Space	*??*

Facility Parameter	(Minimum) Requirement
Power	*??*
Workbenches/Desks	*??*
Heat/AC Load	*??*
LAN Service/Phones	*??*
Environmental Test Support	*??*
EMI/EMC Test Support	*??*

10.1.2 Test Resource Requirements

Table 10.1.2-1 below contains the test resource requirements needed to support system integration.

Table 10.1.2-1 - System I&V Test Resource Requirements

Item	Description	Qty	Specification Number (If Applicable)
Automated Test Systems	*??*	*??*	*??*
Customer Furnished	*??*	*??*	*??*
Computer Workstations	*??*	*??*	*??*
Test Fixtures	*??*	*??*	*??*
Software Tools	*??*	*??*	*??*
Test Instruments	*??*	*??*	*??*
Consumables/Hand tools	*??*	*??*	*??*

Table 10.1.2-2 below contains the test resource requirements needed to support system verification.

Table 10.1.2-2 - System I&V Test Resource Requirements

Item	Description	Qty	Specification Number (If Applicable)
Automated Test Systems	*??*	*??*	*??*
Customer Furnished	*??*	*??*	*??*
Computer Workstations	*??*	*??*	*??*
Software Tools	*??*	*??*	*??*
Environmental Test Systems	*??*	*??*	*??*

Item	Description	Qty	Specification Number (If Applicable)
EMI/EMC Test Equipment	*??*	*??*	*??*
Test Instruments	*??*	*??*	*??*
Test Fixtures	*??*	*??*	*??*
Consumables/Handtools	*??*	*??*	*??*

10.2 System Validation Facility and Test Resource Requirements

10.2.1 Facility Resource Requirements

Table 10.2.1-1 contains the facility requirements needed to support system validation.

Table 10.2.1-1 - System Validation Facility Requirements

Facility Parameter	(Minimum) Requirement
Security Level	*??*
Floor Space	*??*
Power	*??*
Workbenches/Desks	*??*
Heat/AC Load	*??*
LAN Service/Phones	*??*
Environmental Test Support	*??*
EMI/EMC Test Support	*??*

10.2.2 Test Resources

Table 10.2.2-1 below contains the test resource requirements needed to support system validation.

Table 10.2.2-1 - System Validation Test Resource Requirements

Item	Description	Qty	Specification Number (If Applicable)
Automated Test Systems	*??*	*??*	*??*
Customer Furnished	*??*	*??*	*??*
Computer Workstations	*??*	*??*	*??*
Software Tools	*??*	*??*	*??*
Environmental Test Systems	*??*	*??*	*??*

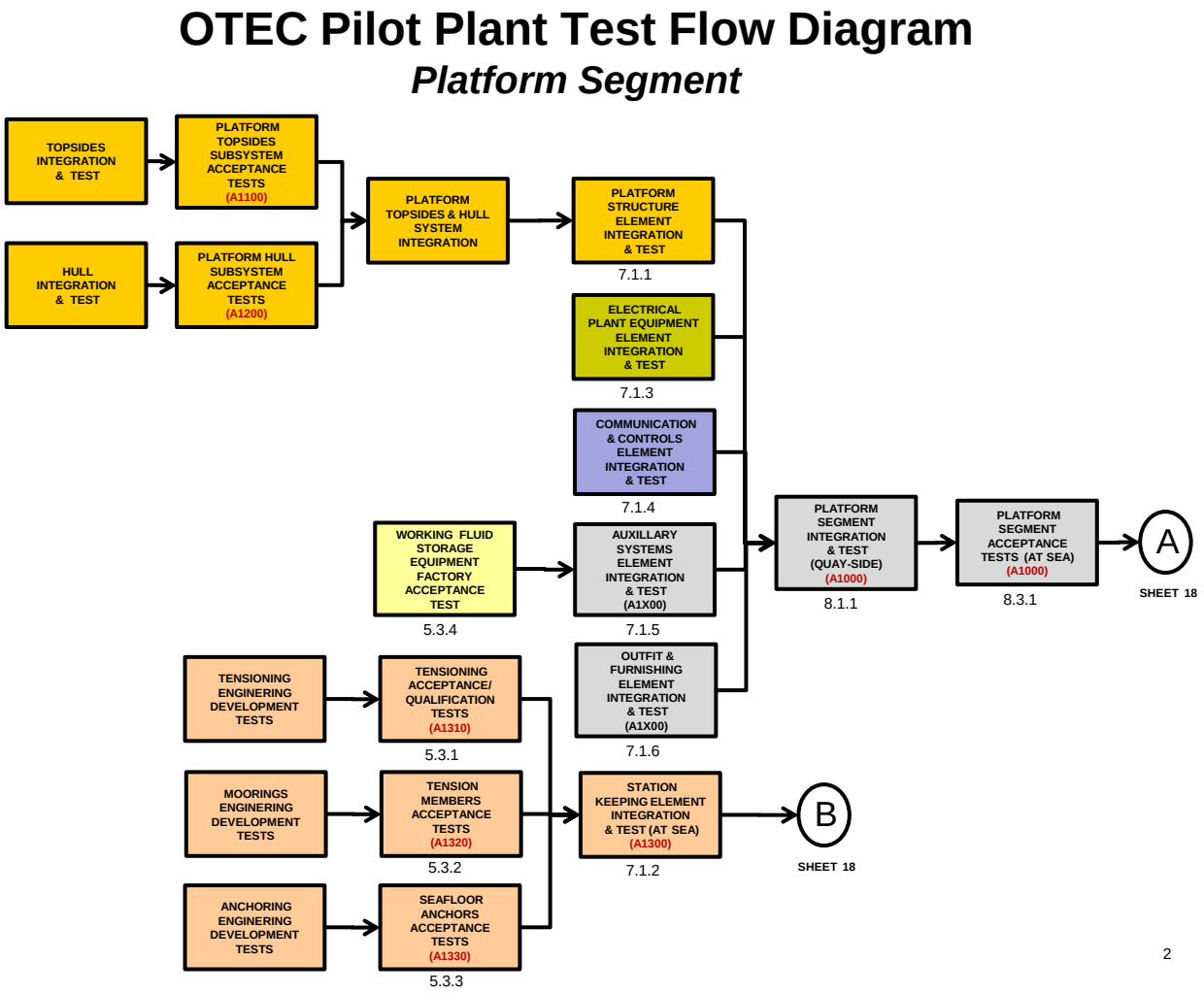
Item	Description	Qty	Specification Number (If Applicable)
EMI/EMC Test Equipment	*??*	*??*	*??*
Test Instruments	*??*	*??*	*??*
Test Fixtures	*??*	*??*	*??*
Consumables/Hand tools	*??*	*??*	*??*

Appendix A – Acronyms & Abbreviations

Acronym/Abbreviation	Definition
ABS	American Bureau of Shipping
AC	Air Conditioning
CDRL	Contract Deliverable Requirements List
CONOPS	Concept of Operations
CW	Cold Water
CWP	Cold Water Pipe
DOD	Department of Defense
DOE	Department of Energy
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EPA	Environmental Protection Agency
HVAC	Heating, Ventilation and Air Conditioning
Hx	Heat Exchanger
II&C	Integrated Instrumentation & Control
INCO	Installation and Checkout
KW	Kilowatt
LAN	Local Area Network
LM	Lockheed Martin
m	meter
MTP	Master Test Plan
MW	Megawatt
NAVFAC	Naval Facilities Engineering Command
NOAA	National Oceanographic and Atmospheric Administration
OTEC	Ocean Thermal Energy Conversion
Qty	Quantity
RVTM	Requirements Verification Traceability Matrix
SCADA	Supervisory Control and Data Acquisition
SoS	System of Systems
TBD	To Be Determined
TBS	To Be Supplied

Acronym/Abbreviation	Definition
WF	Working Fluid
WW	Warm Water
US	United States

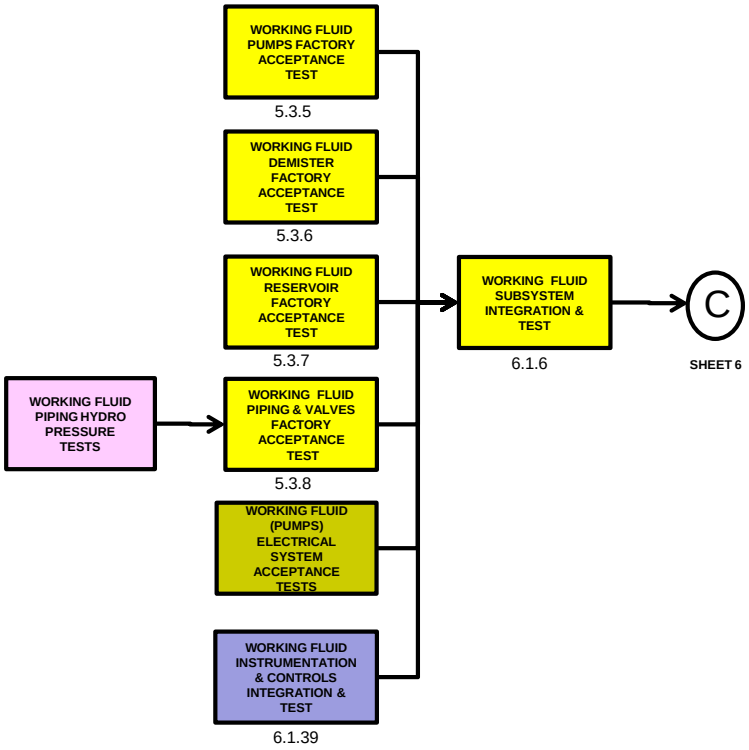
APPENDIX B – Test Flow Diagram/sequence network



OTEC Pilot Plant Test Flow Diagram

Working Fluid (Ammonia) Handling Subsystem

Power Cycle (Remora) Element - Power Generation Segment

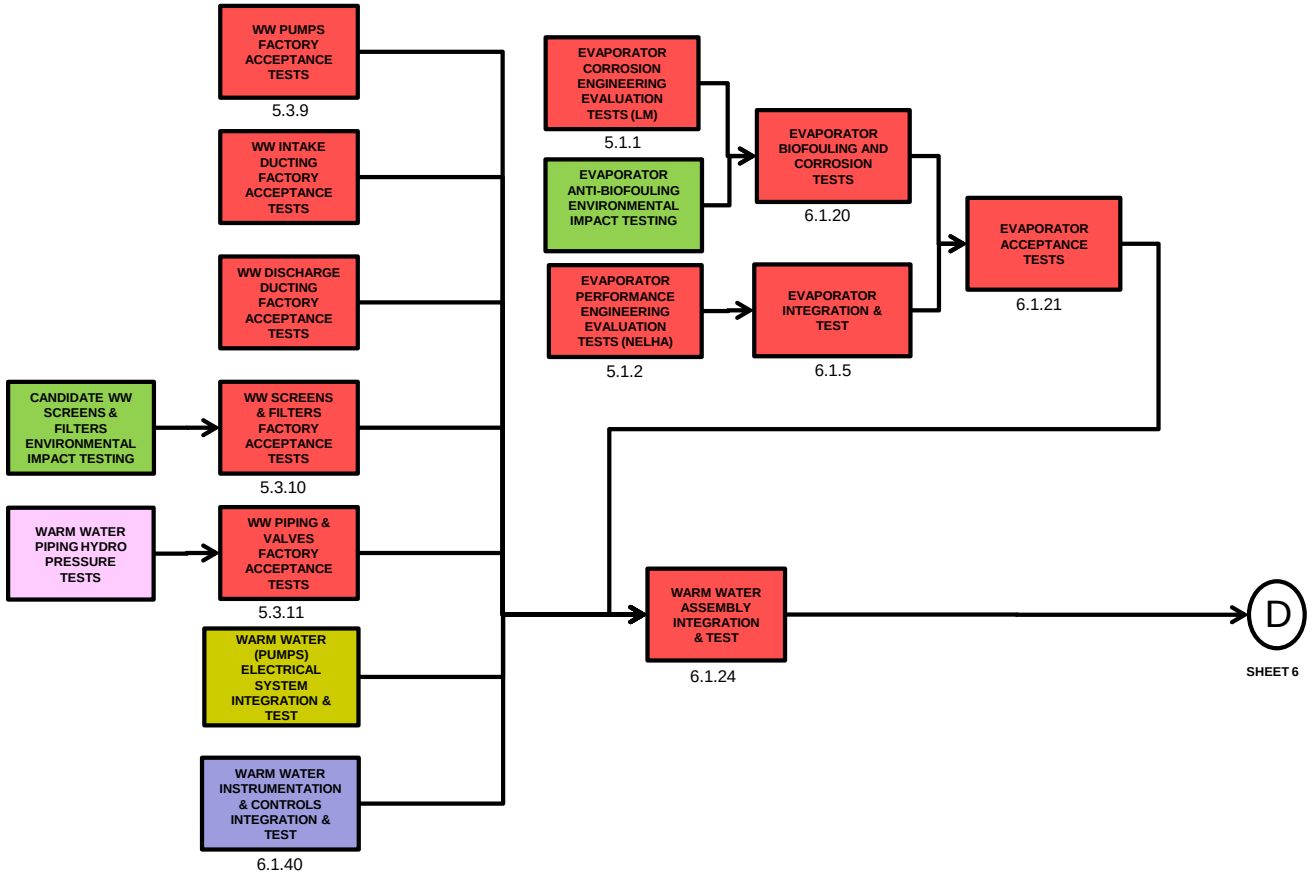


3

OTEC Pilot Plant Test Flow Diagram

Warm Water Handling Subsystem

Power Cycle (Remora) Element - Power Generation Segment

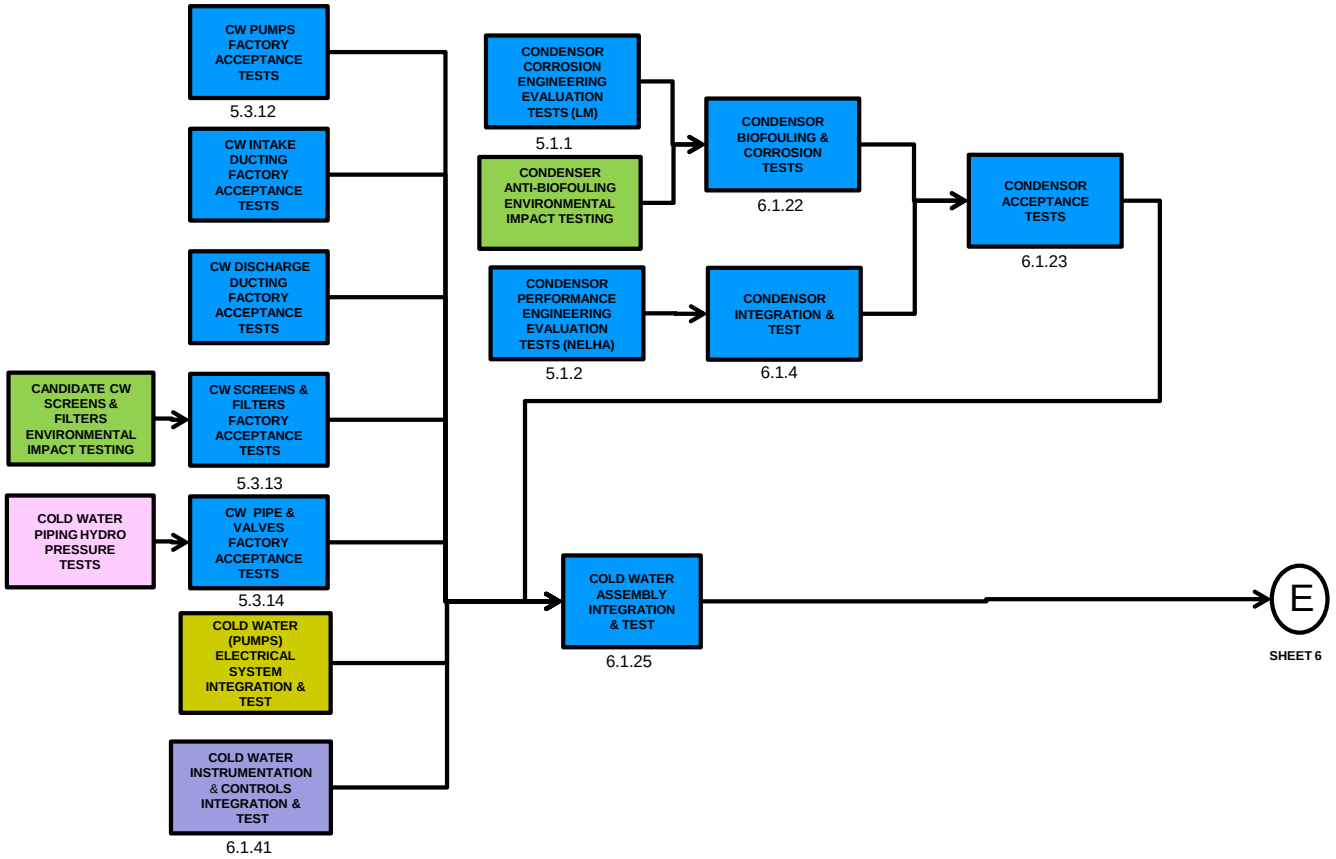


4

OTEC Pilot Plant Test Flow Diagram

Cold Water Handling Subsystem

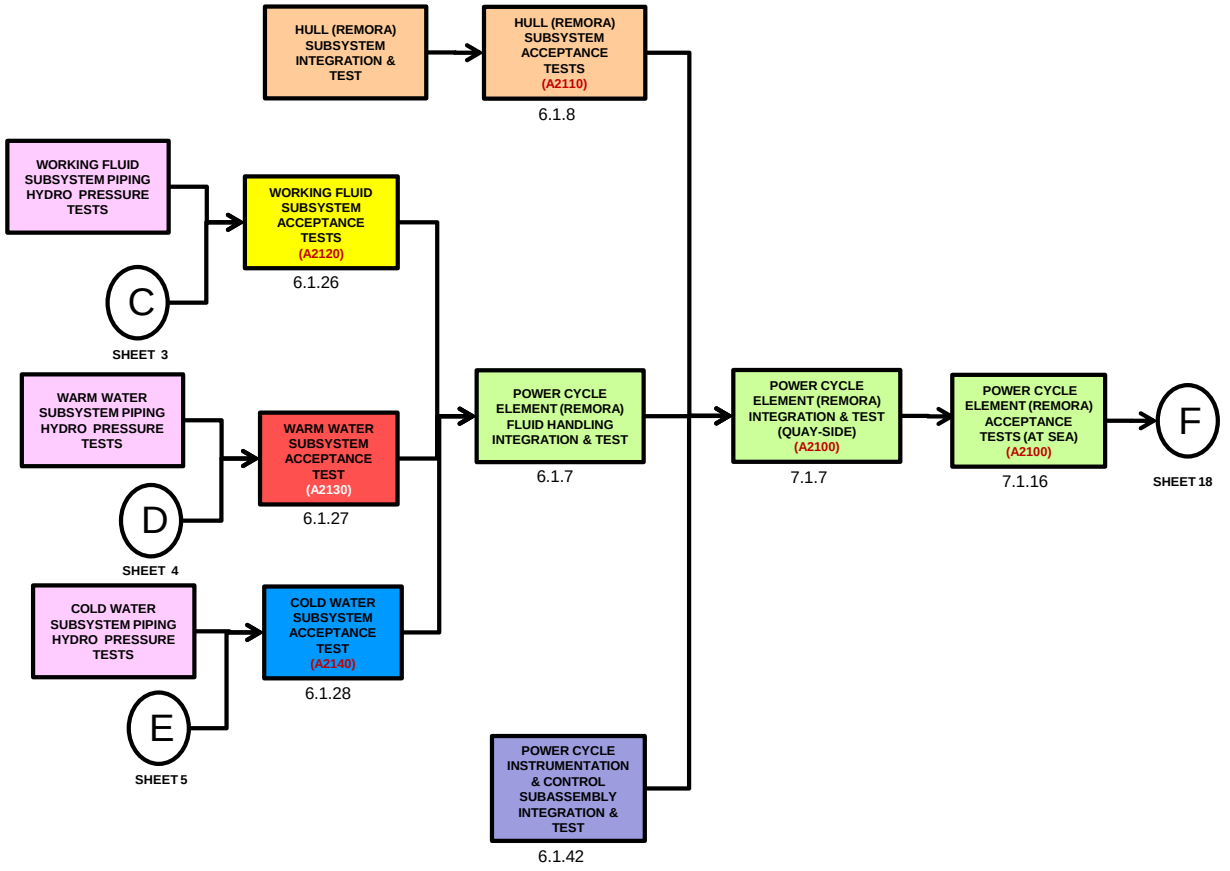
Power Cycle (Remora) Element - Power Generation Segment



5

OTEC Pilot Plant Test Flow Diagram

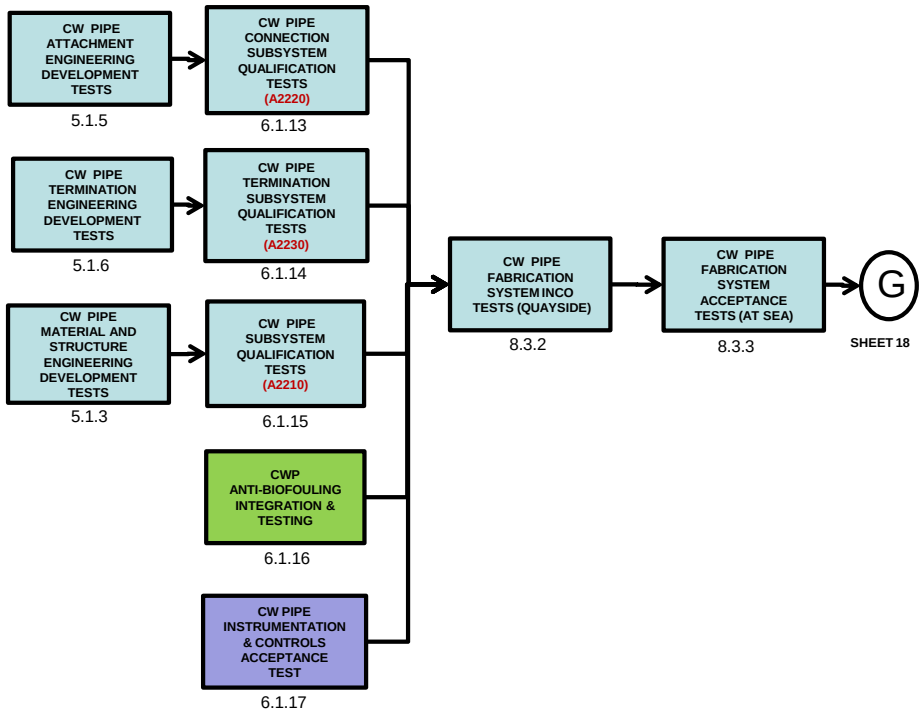
Power Cycle (Remora) Element - Power Generation Segment



6

OTEC Pilot Plant Test Flow Diagram

Cold Water Pipe (CWP) Element - Power Generation Segment

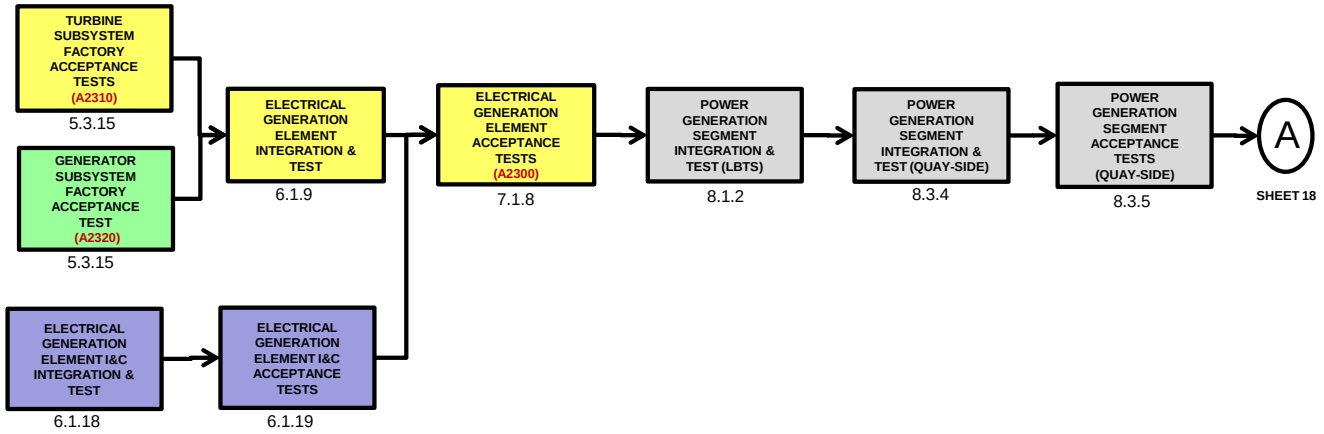


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OTEC Pilot Plant Test Flow Diagram

Turbine & Generator Subsystems

Electrical Generation Element - Power Generation Segment

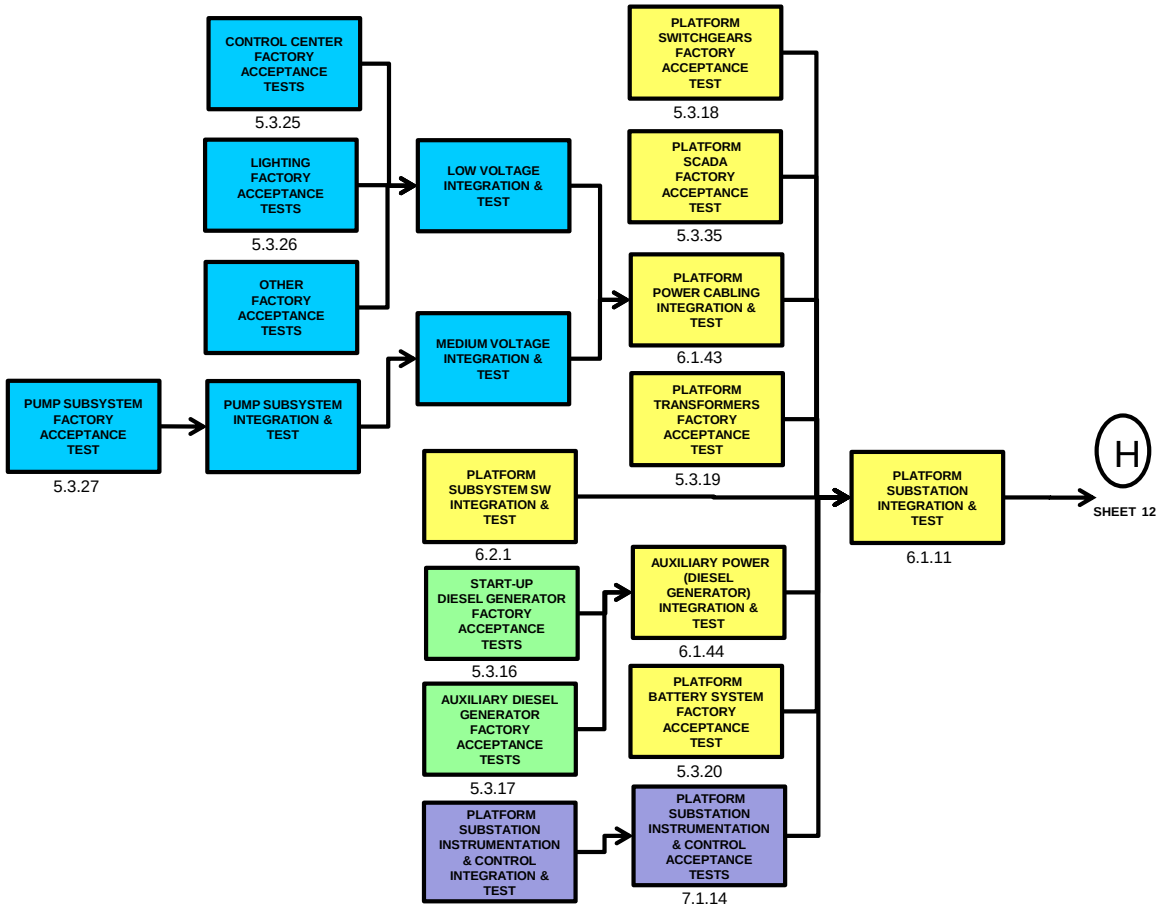


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OTEC Pilot Plant Test Flow Diagram

Platform Substation Subsystem

Electrical Delivery Element - Power Delivery Segment

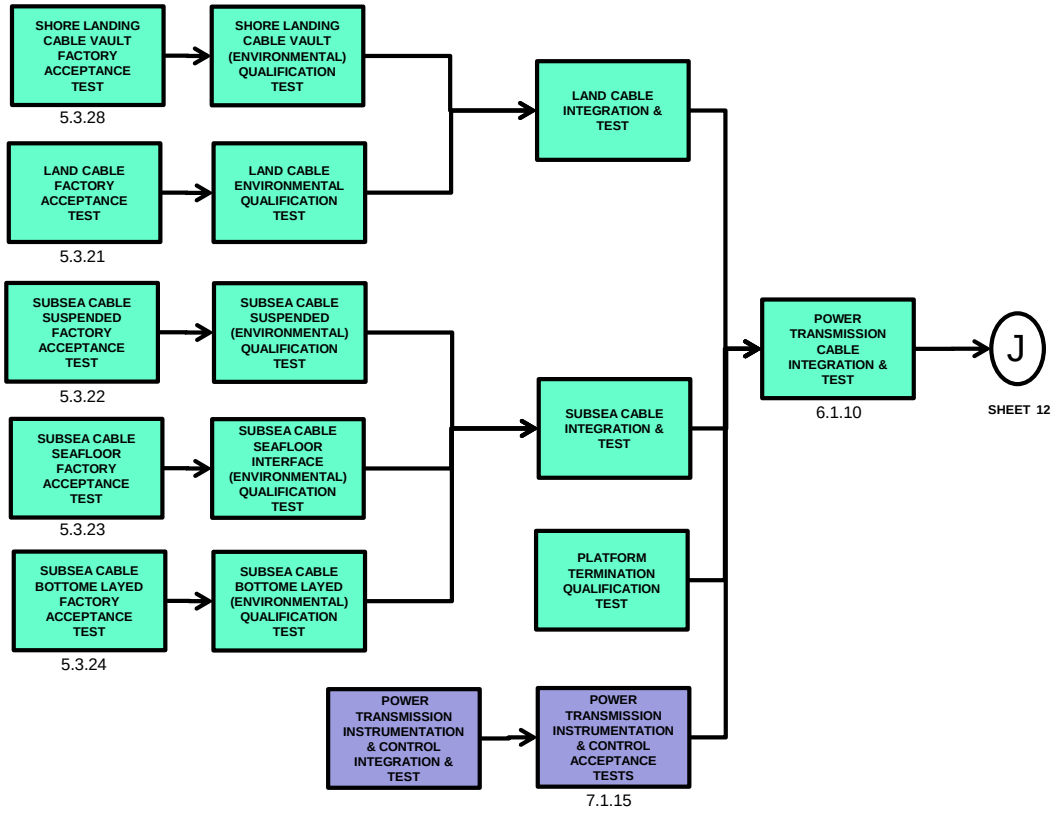


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OTEC Pilot Plant Test Flow Diagram

Power Transmission Subsystem

Electrical Delivery Element - Power Delivery Segment

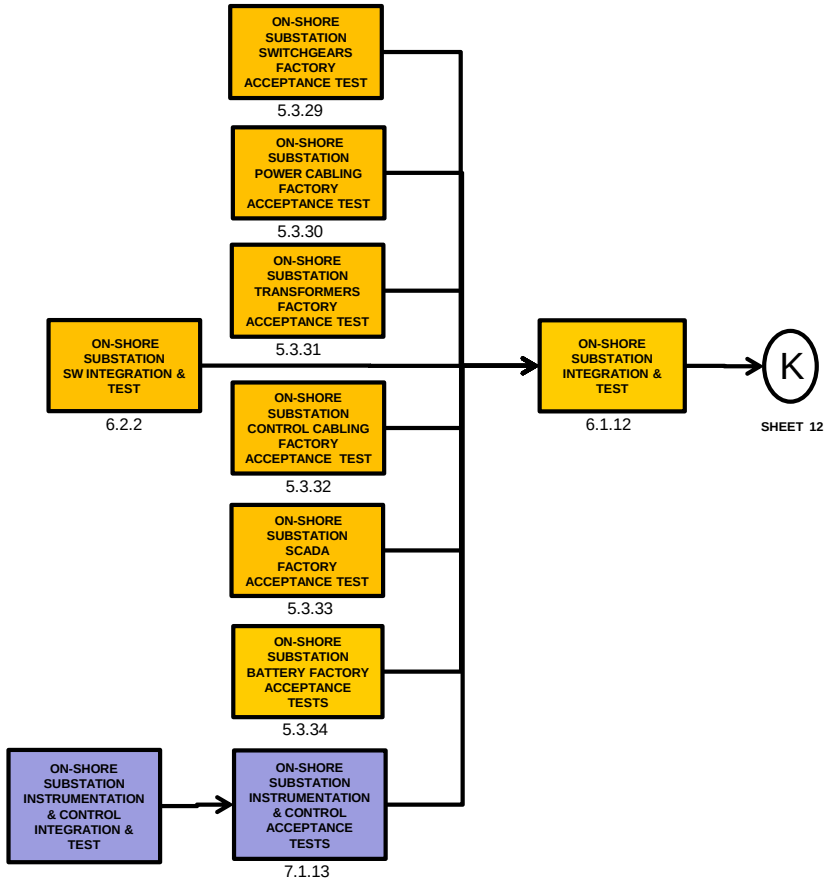


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OTEC Pilot Plant Test Flow Diagram

Onshore Substation Subsystem

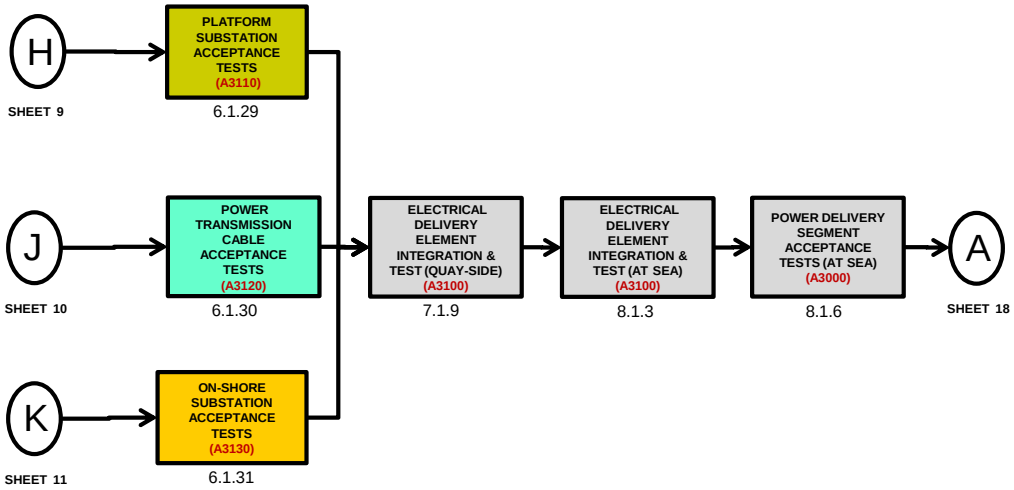
Electrical Delivery Element - Power Delivery Segment



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OTEC Pilot Plant Test Flow Diagram

Electrical Delivery Element - Power Delivery Segment



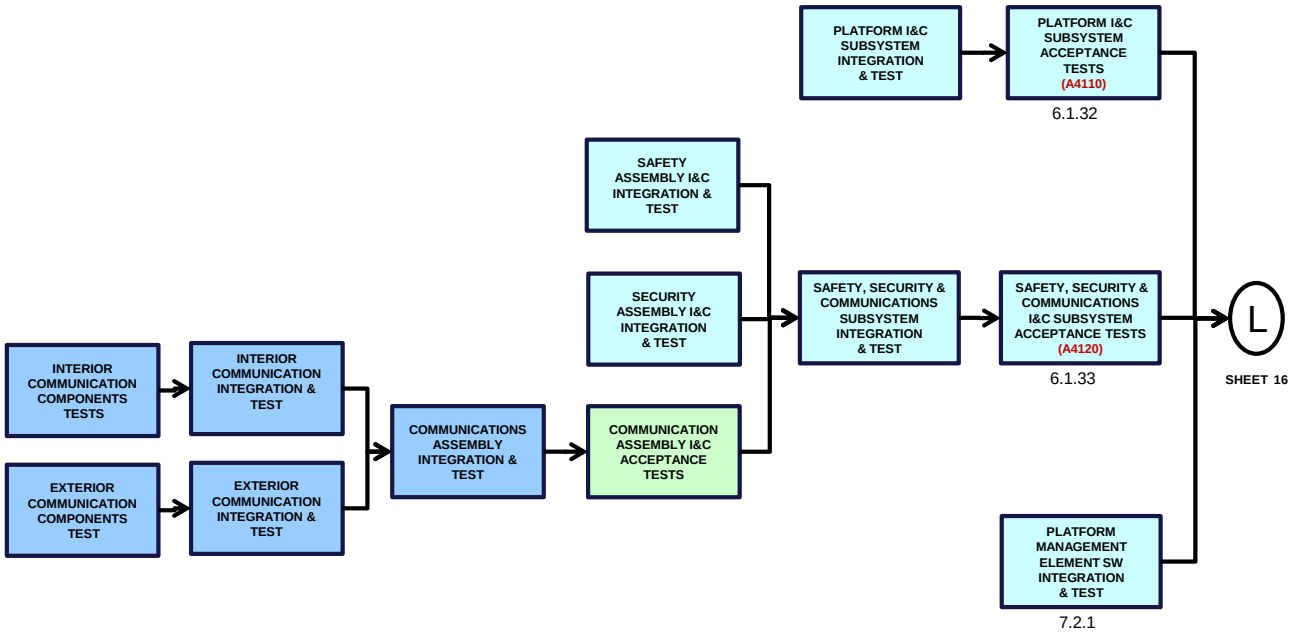
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OTEC Pilot Plant Test Flow Diagram

Platform and Safety, Security & Communications Subsystems

Platform Management Element

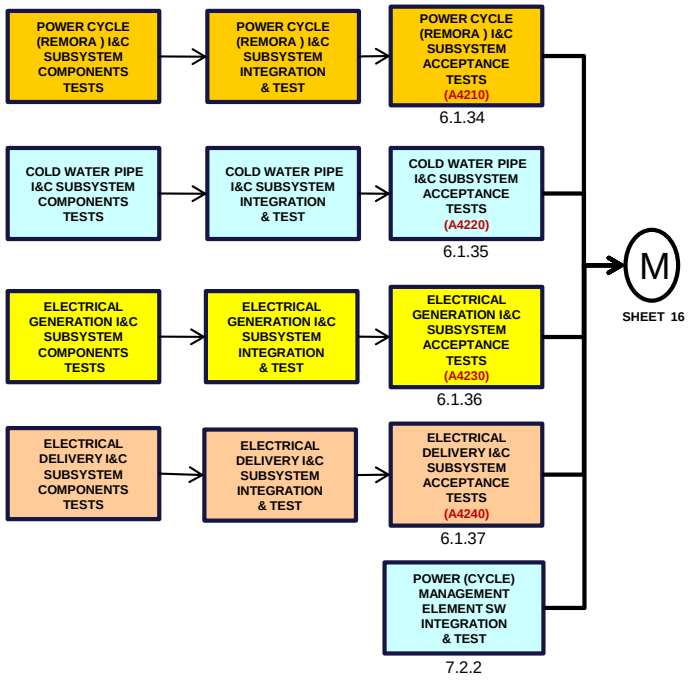
Integrated Instrumentation & Control (I&C) Segment



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OTEC Pilot Plant Test Flow Diagram

Power Cycle, CWP, and Electrical Generation, and Electrical Delivery Subsystems - Power Management Element Integrated Instrumentation & Control (I&C) Segment



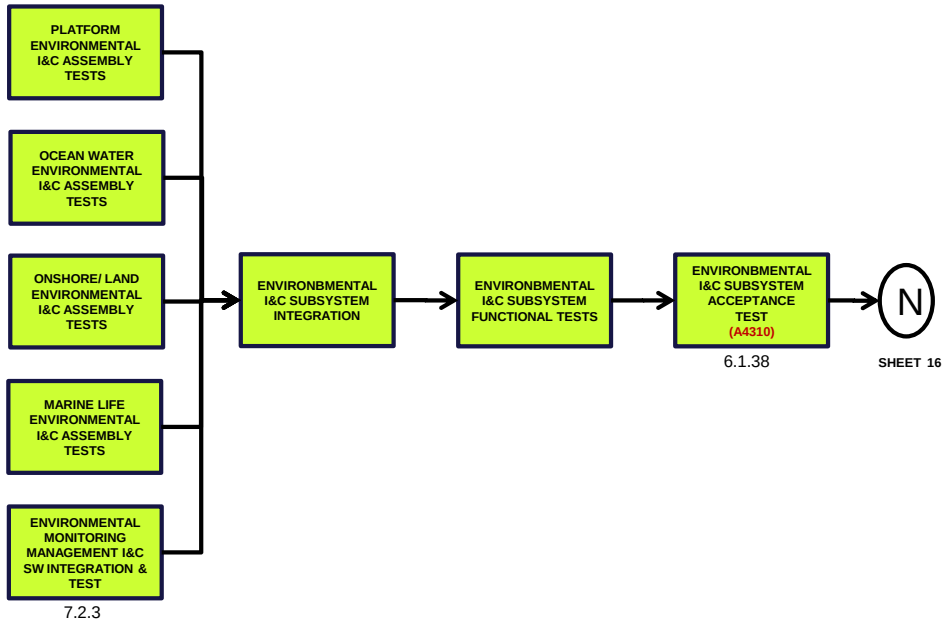
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OTEC Pilot Plant Test Flow Diagram

Environmental I&C Subsystem

Environmental Monitoring Management Element

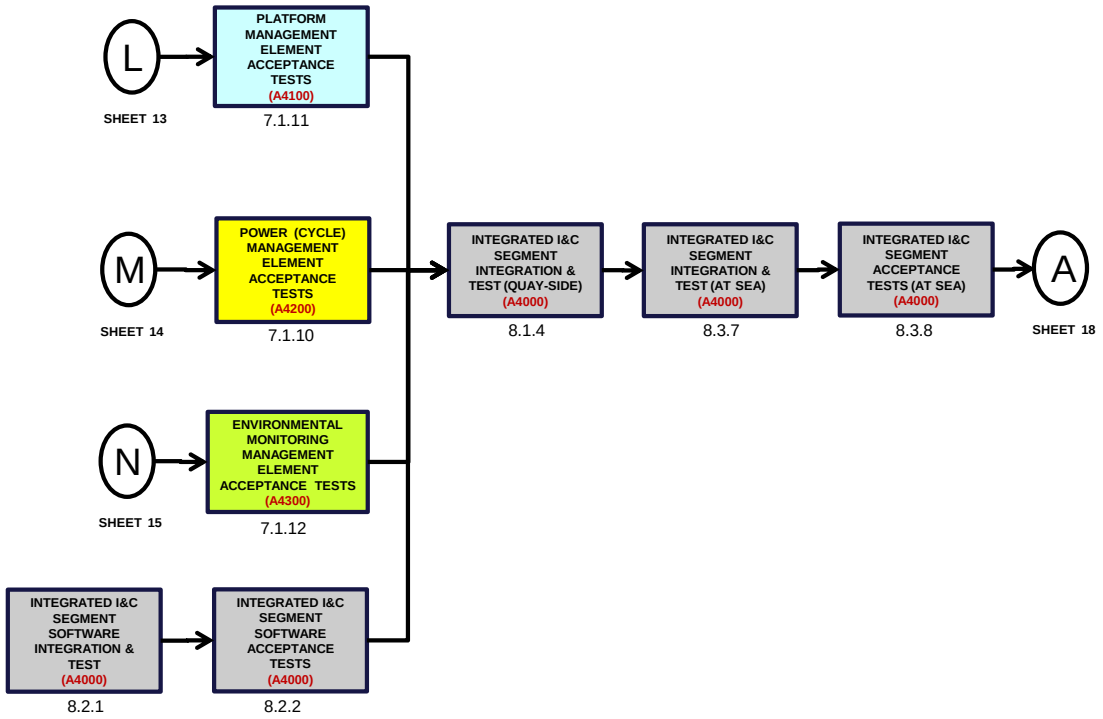
Integrated Instrumentation & Control (I&C) Segment



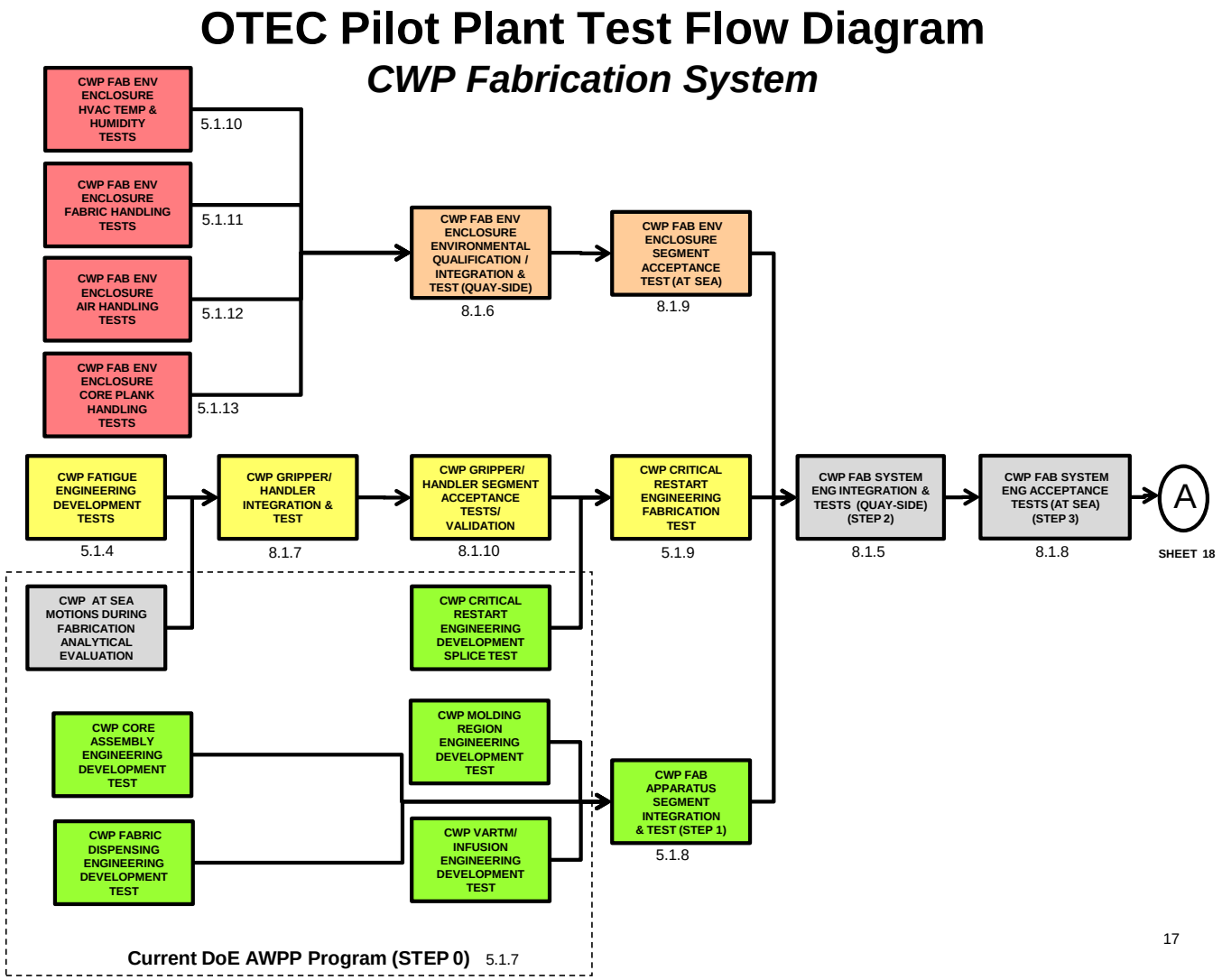
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OTEC Pilot Plant Test Flow Diagram

Integrated Instrumentation & Control (I&C) Segment

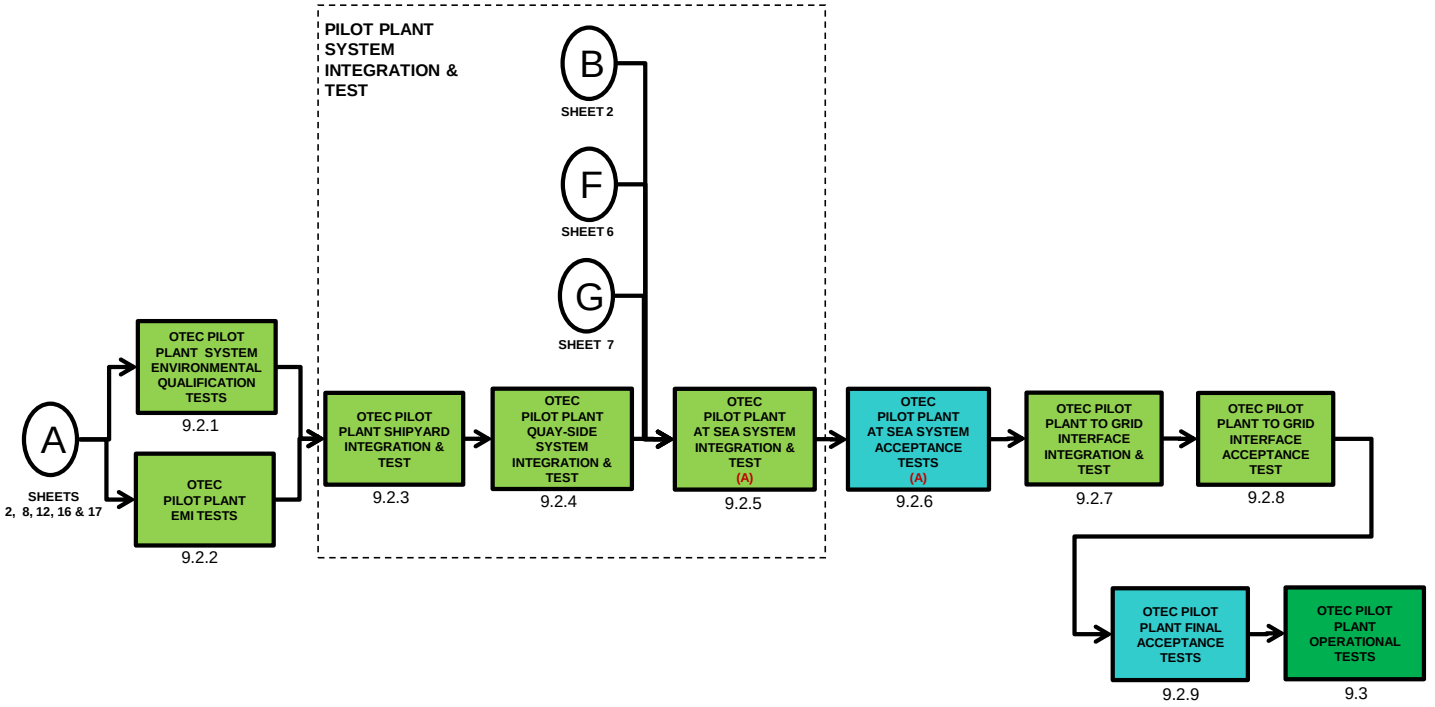


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OTEC Pilot Plant Test Flow Diagram
CWP Fabrication System
CWP FAB ENV ENCLOSURE HVAC TEMP & HUMIDITY TESTS
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CWP FAB ENV ENCLOSURE FABRIC HANDLING TESTS
5.1.11
CWP FAB ENV ENCLOSURE AIR HANDLING TESTS
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CWP FAB ENV ENCLOSURE CORE PLANK HANDLING TESTS
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OTEC Pilot Plant Test Flow Diagram

OTEC Pilot Plant System



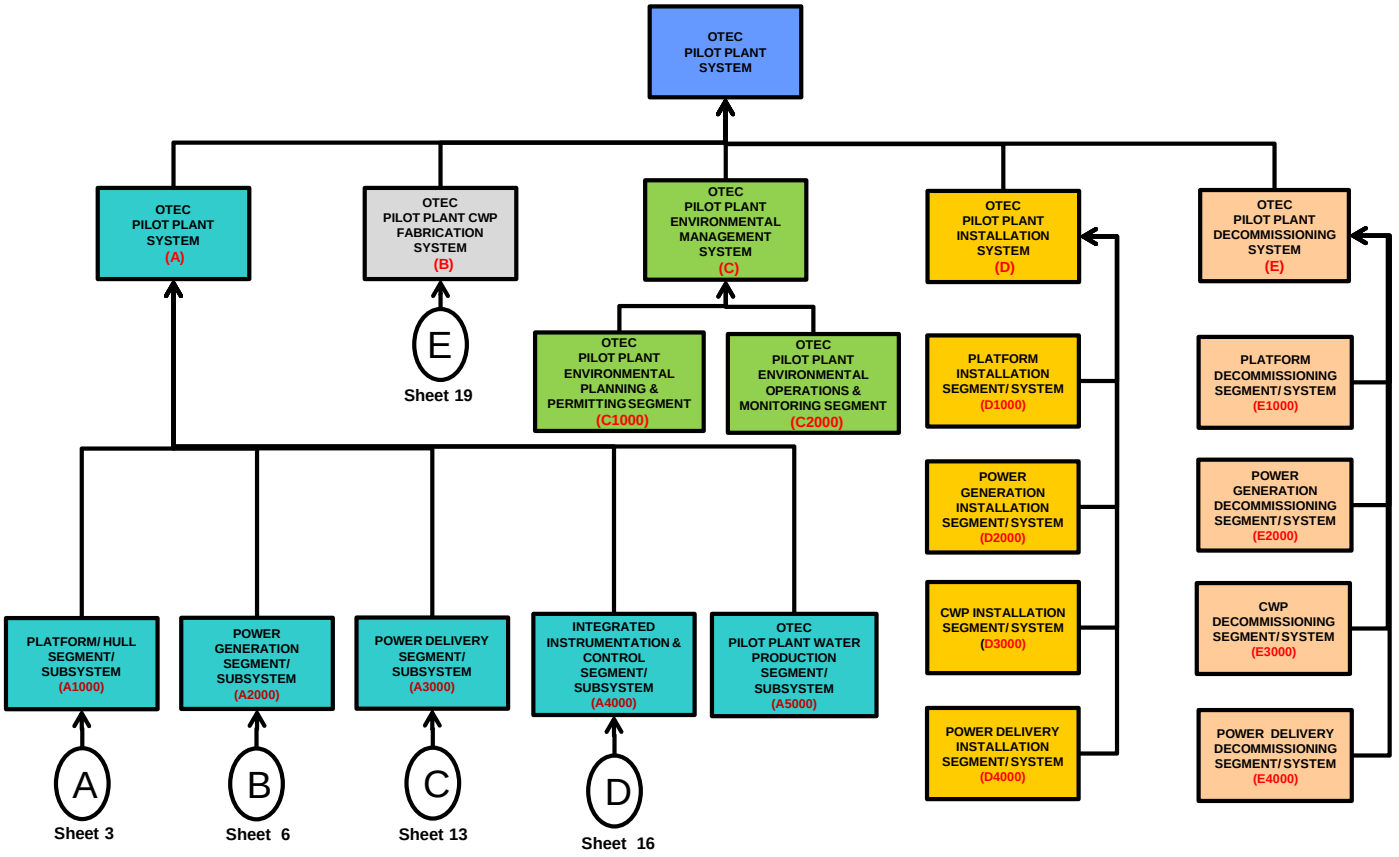
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APPENDIX C – OTEC Pilot Plant Integrated Master Schedule (IMS)

APPENDIX D – OTEC Pilot Plant Physical Architecture Diagram

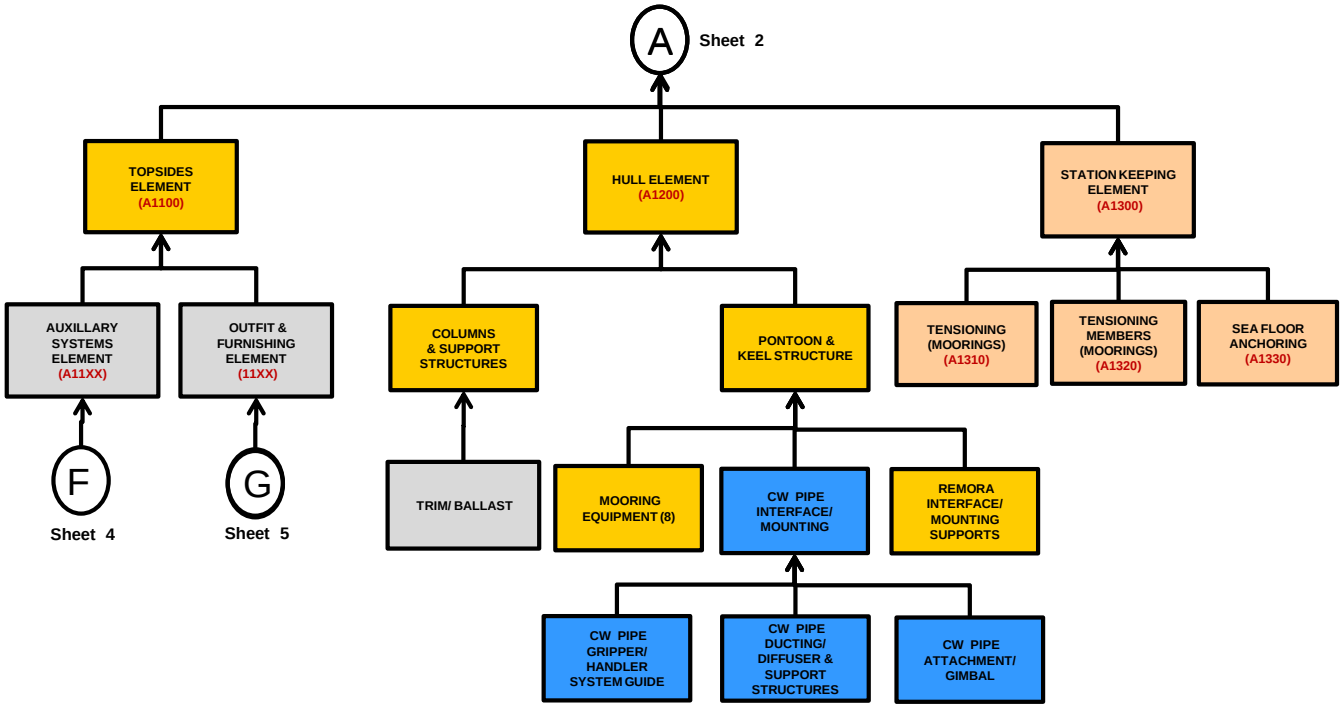
OTEC Pilot Plant Physical Architecture

OTEC Pilot Plant System



OTEC Pilot Plant Physical Architecture

Platform Segment

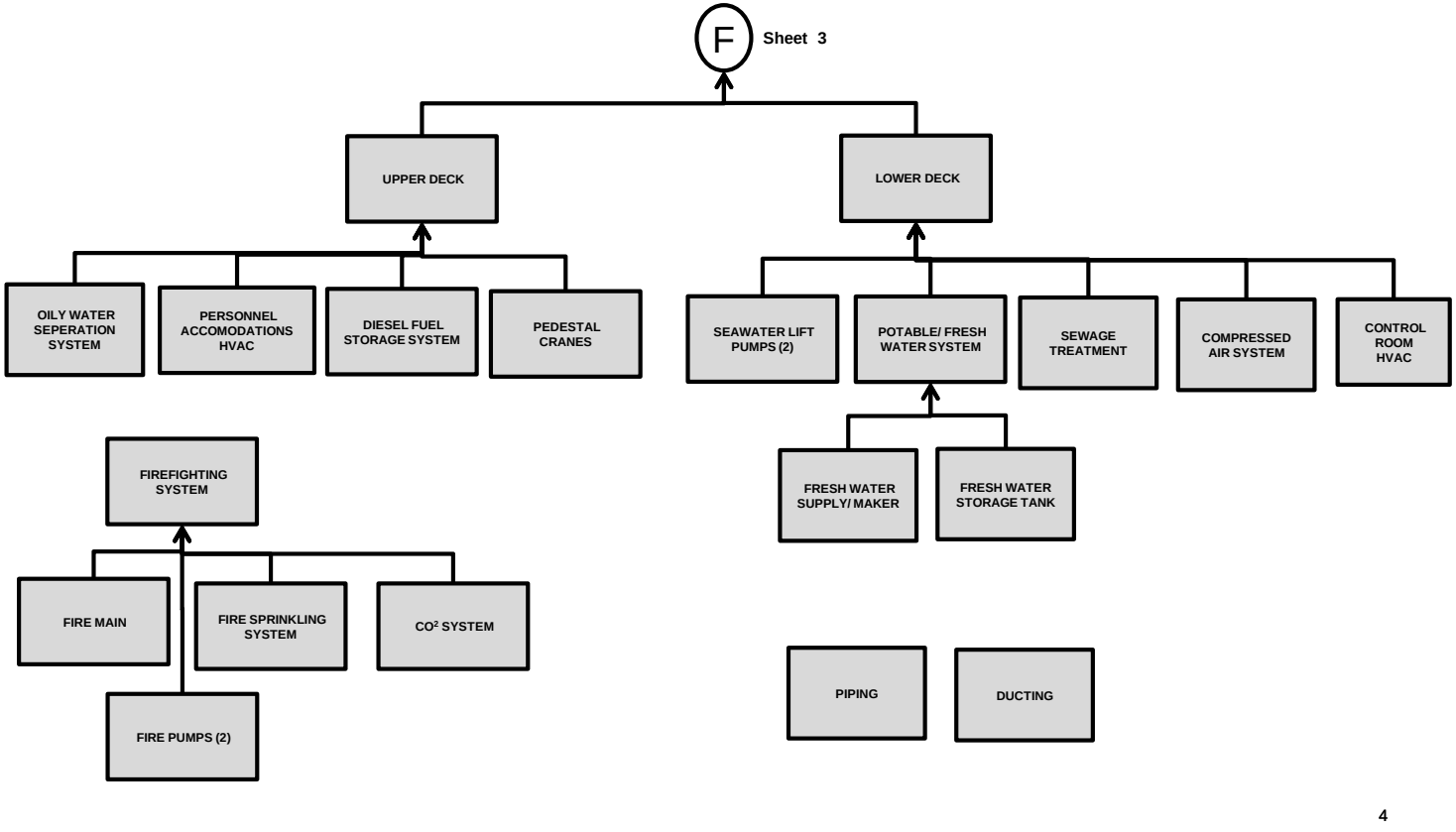


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OTEC Pilot Plant Physical Architecture

Auxiliary Subsystems

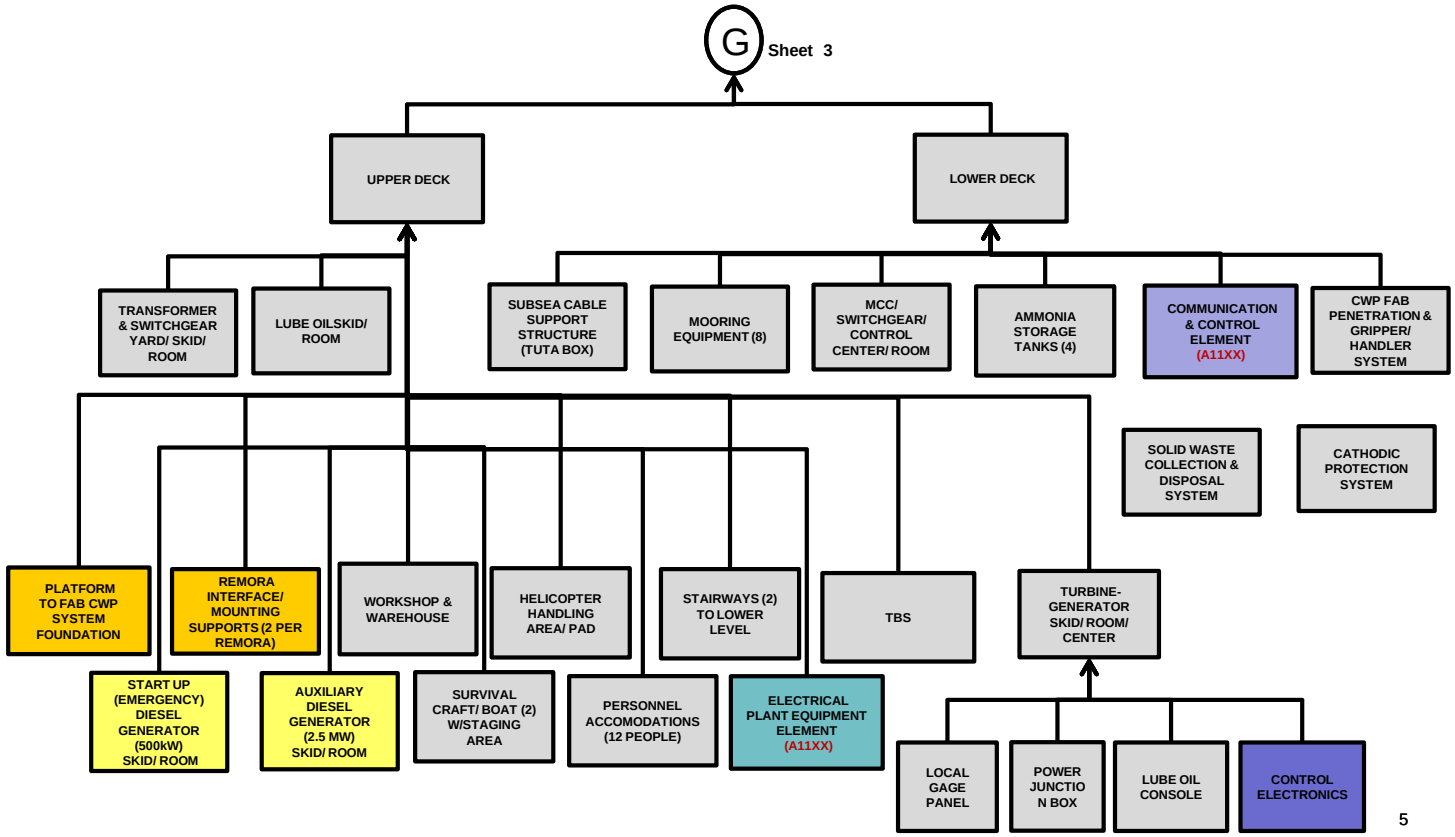
Auxiliary Element - Platform Segment



OTEC Pilot Plant Physical Architecture

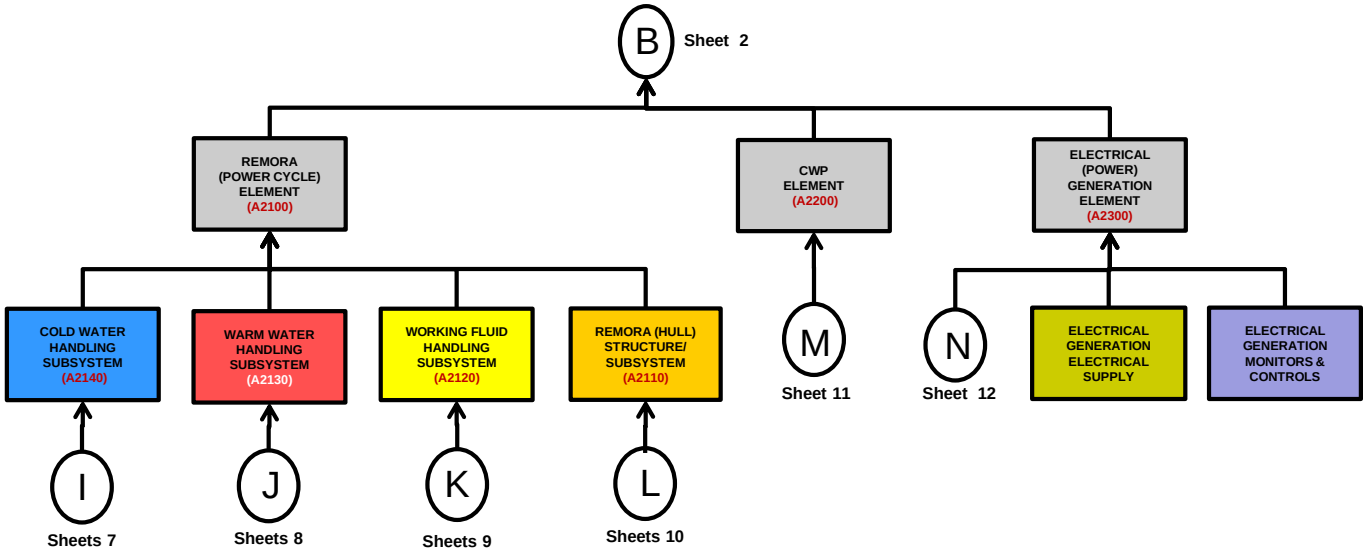
Outfit & Furnishing Subsystems

Outfit & Platform Element - Platform Segment



OTEC Pilot Plant Physical Architecture

Power Generation Segment

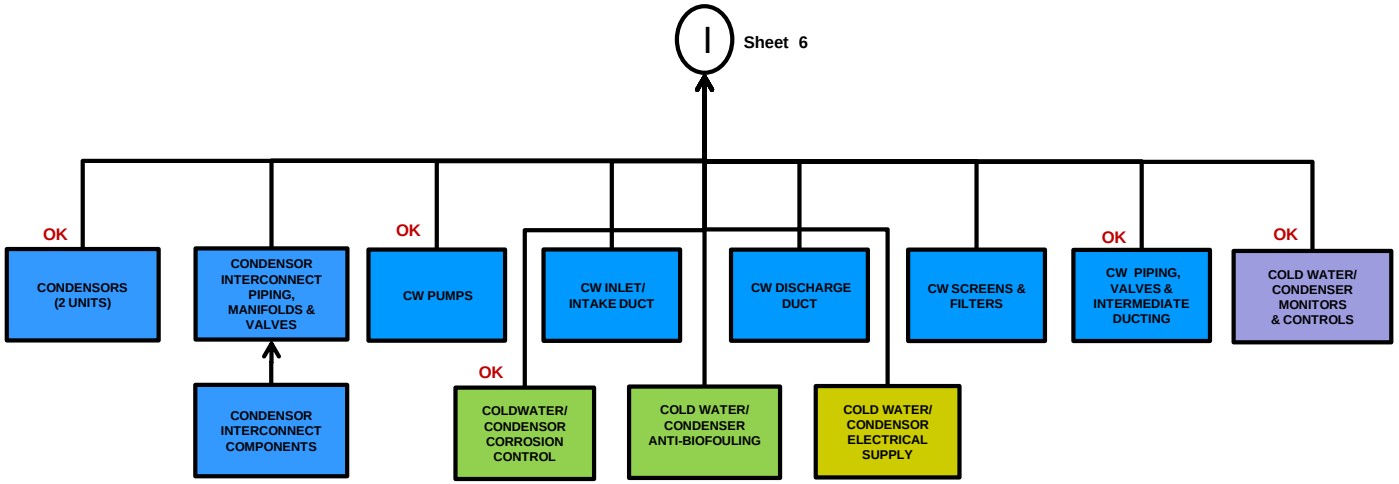


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OTEC Pilot Plant Physical Architecture

Cold Water Handling Subsystem

Power Cycle (Remora) Element - Power Generation Segment

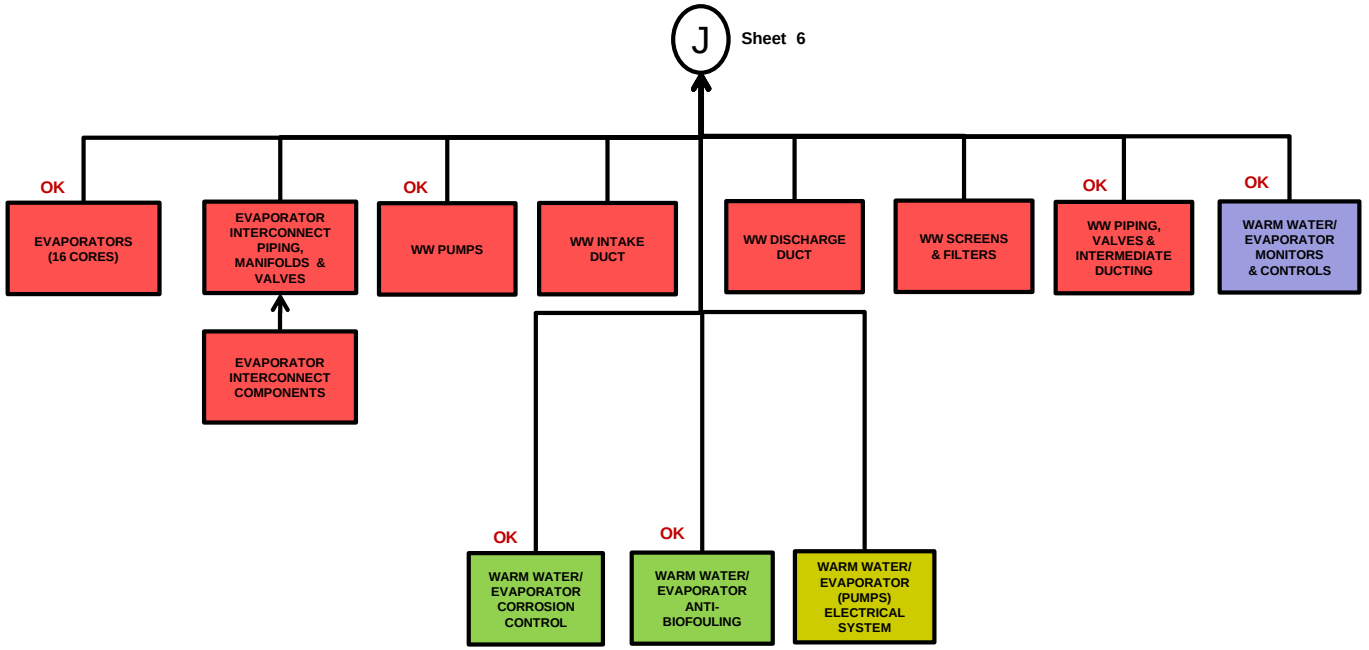


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OTEC Pilot Plant Physical Architecture

Warm Water Handling Subsystem

Power Cycle (Remora) Element - Power Generation Segment

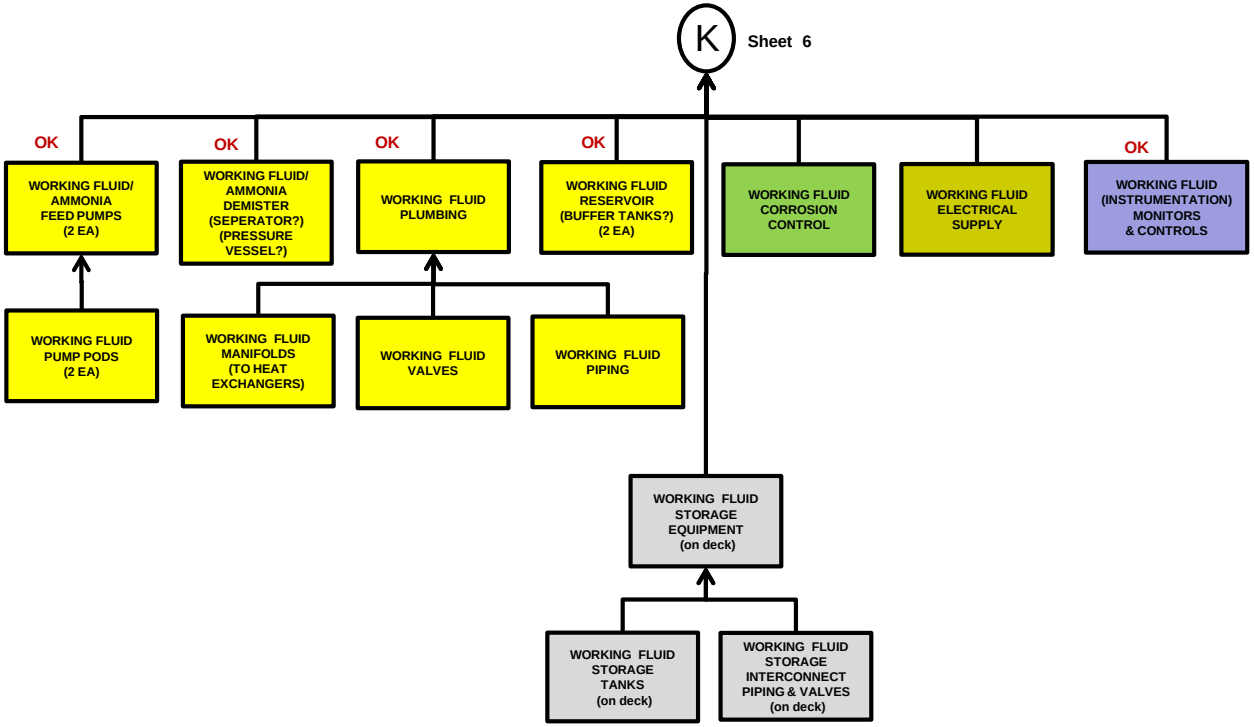


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OTEC Pilot Plant Physical Architecture

Working Fluid (Ammonia) Handling Subsystem

Power Cycle (Remora) Element - Power Generation Segment

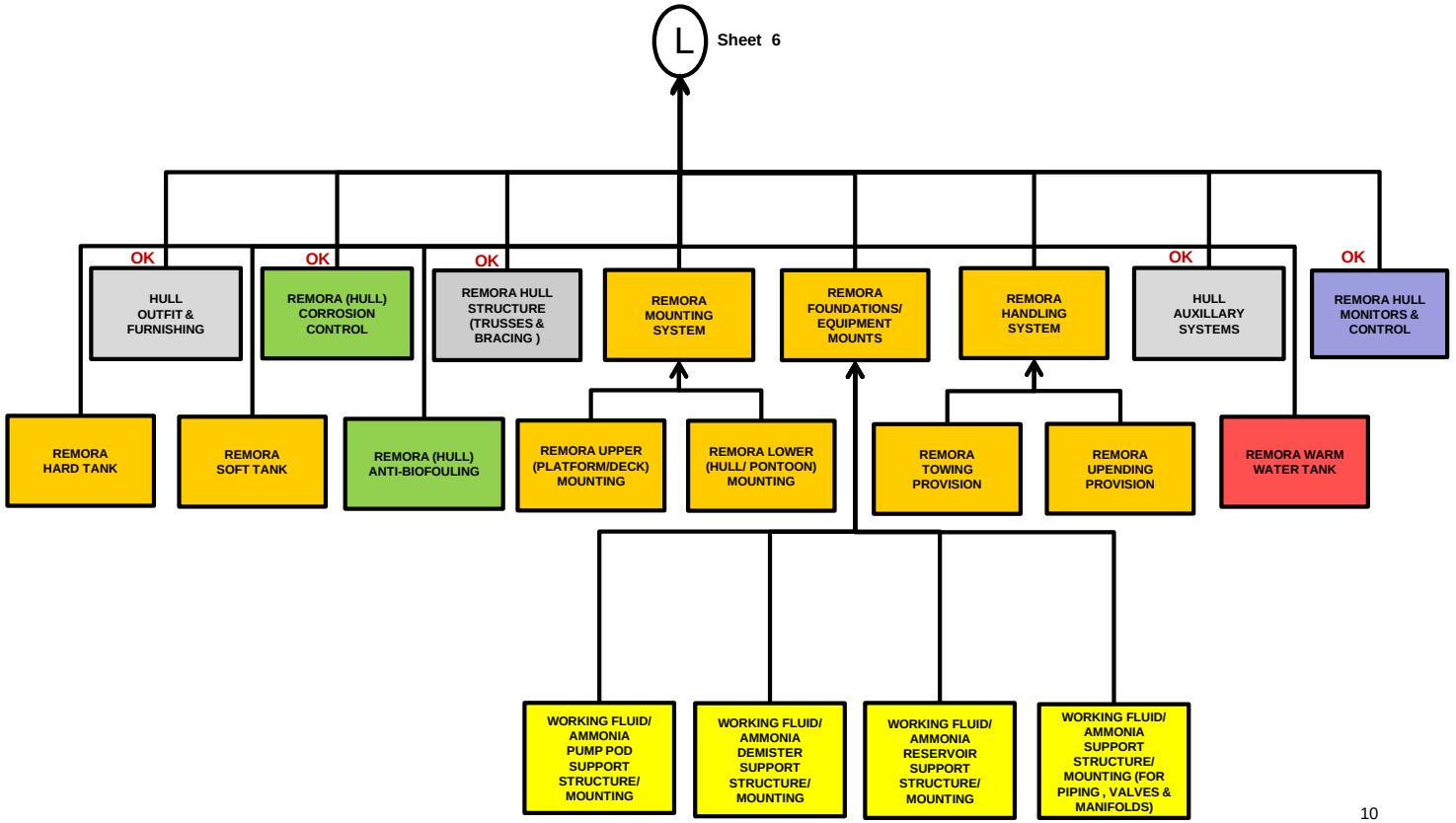


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OTEC Pilot Plant Physical Architecture

Hull/Structure Subsystem

Power Cycle (Remora) Element - Power Generation Segment

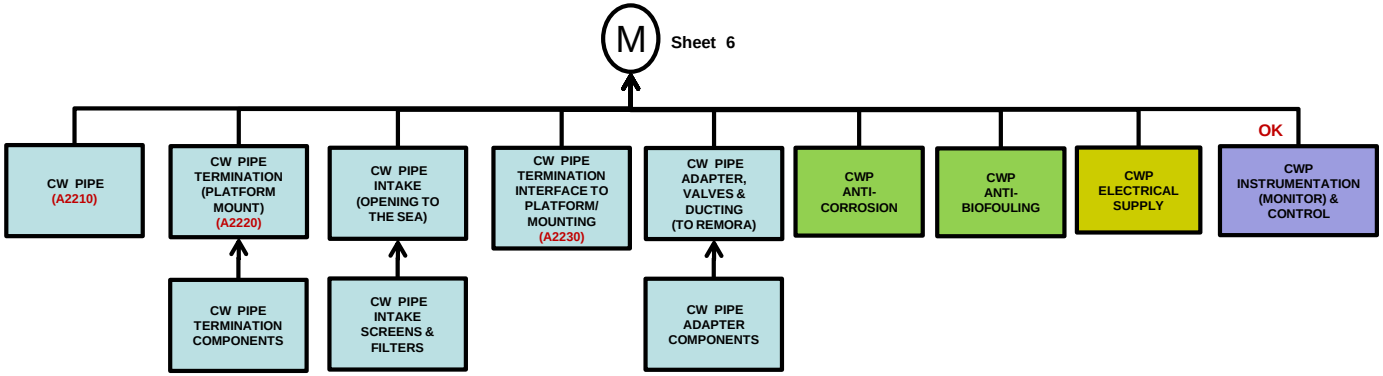


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OTEC Pilot Plant Physical Architecture

Cold Water Pipe (CWP) Element

Power Generation Segment

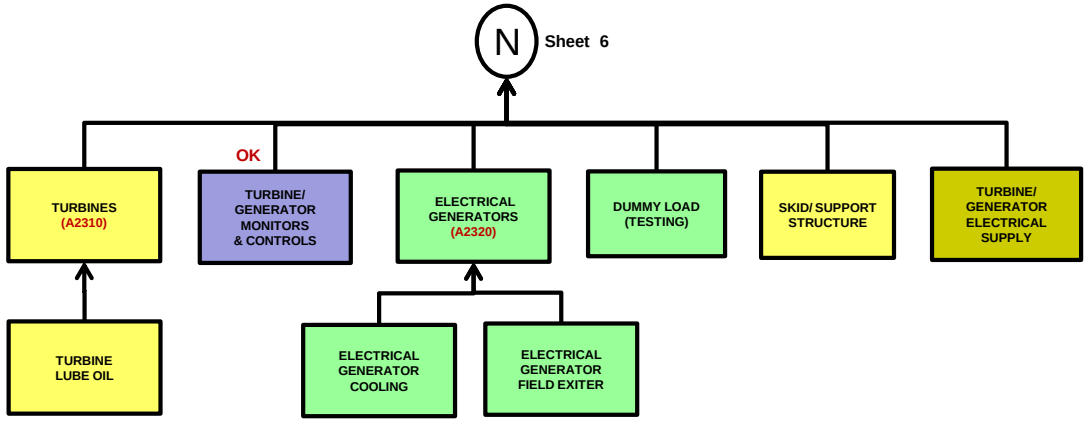


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OTEC Pilot Plant Physical Architecture

Turbine/Generator Subsystem

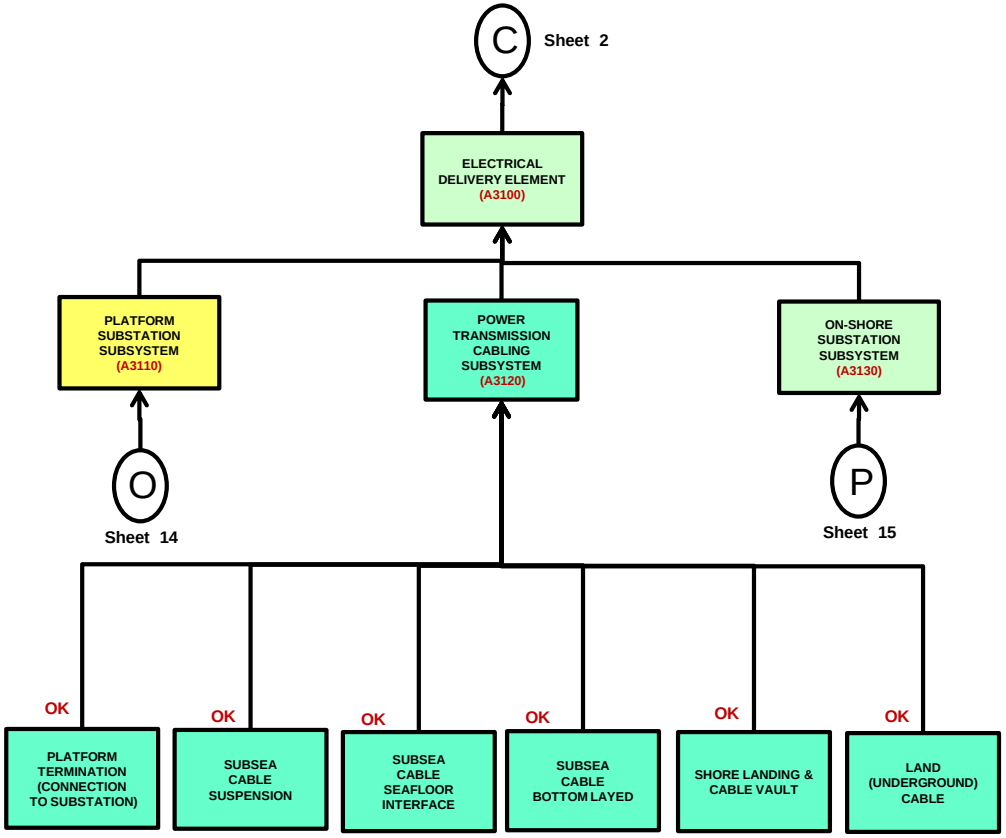
Electrical Generation Element - Power Generation Segment



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OTEC Pilot Plant Physical Architecture

Power Delivery Element – Power Delivery Segment

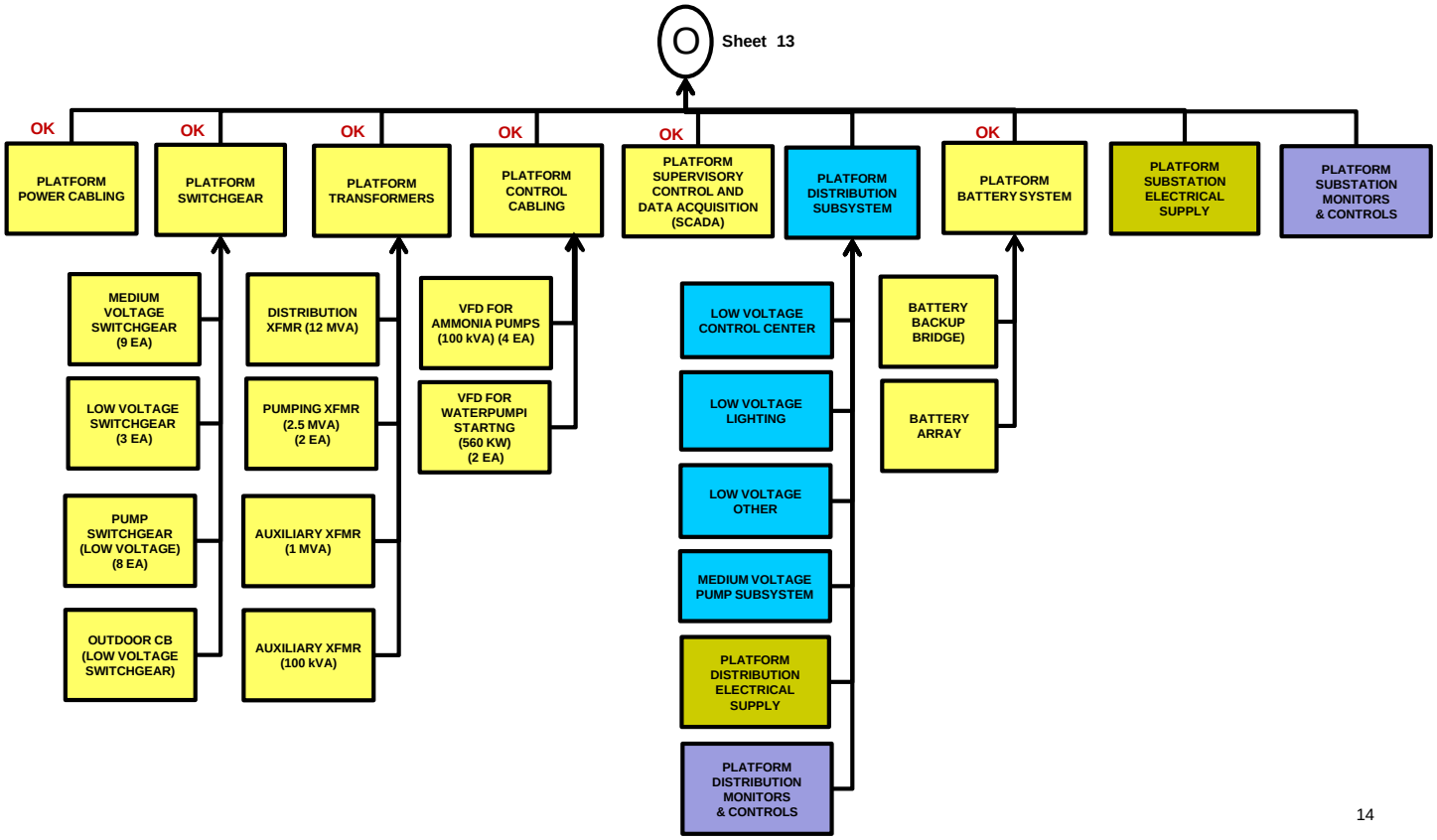


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OTEC Pilot Plant Physical Architecture

Platform Substation Subsystem – Power Delivery Element

Power Delivery Segment

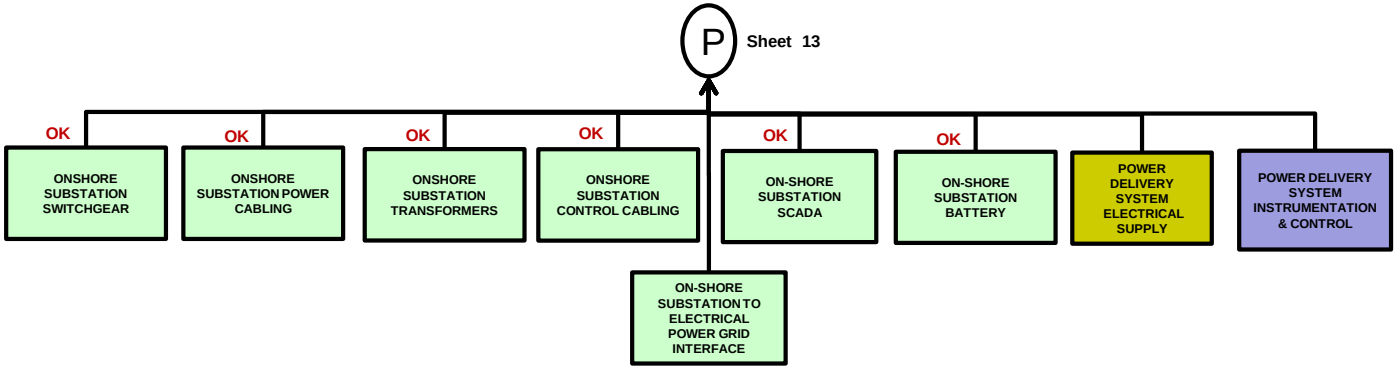


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OTEC Pilot Plant Physical Architecture

On-Shore Substation Subsystem - Power Delivery Element

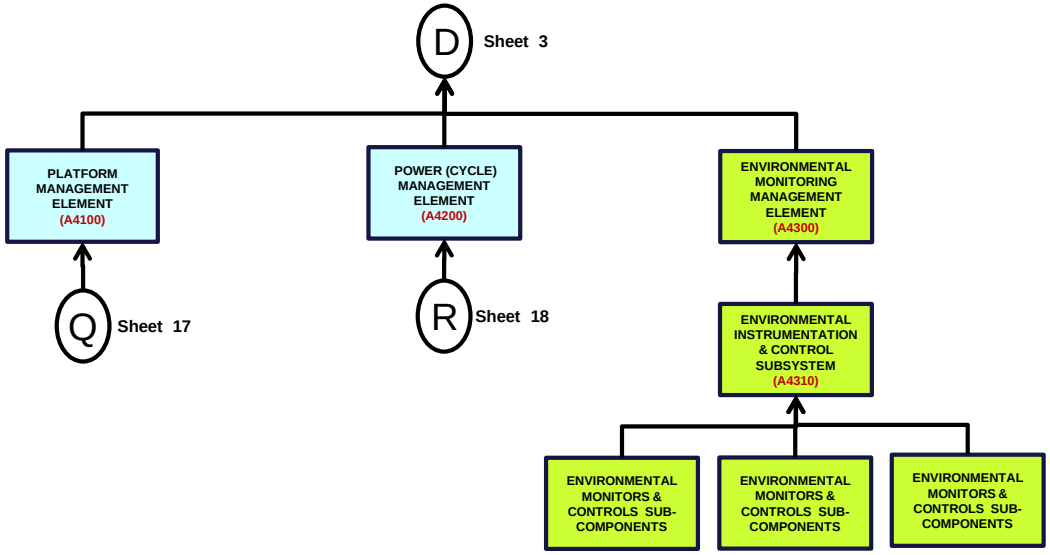
Power Delivery System



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OTEC Pilot Plant Physical Architecture

Integrated Instrumentation & Control Segment

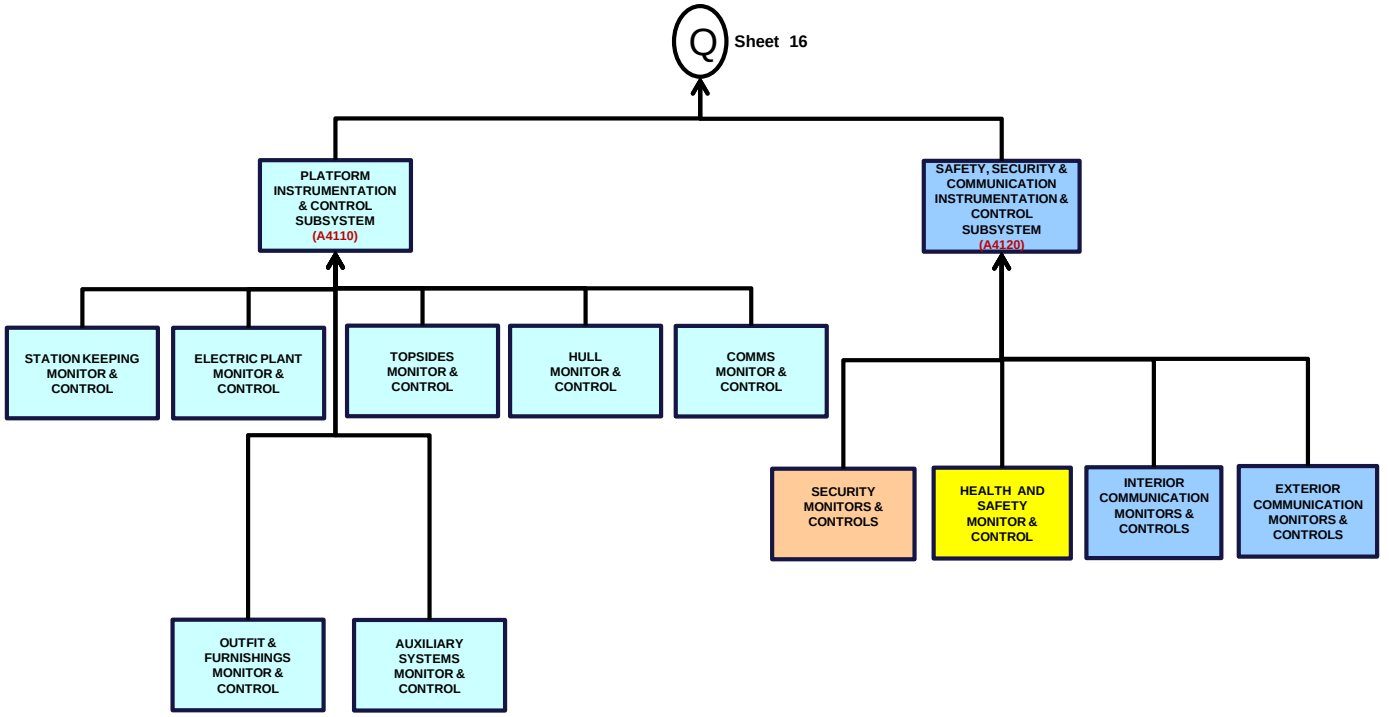


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OTEC Pilot Plant Physical Architecture

Platform Management Element

Integrated Instrumentation & Control Segment

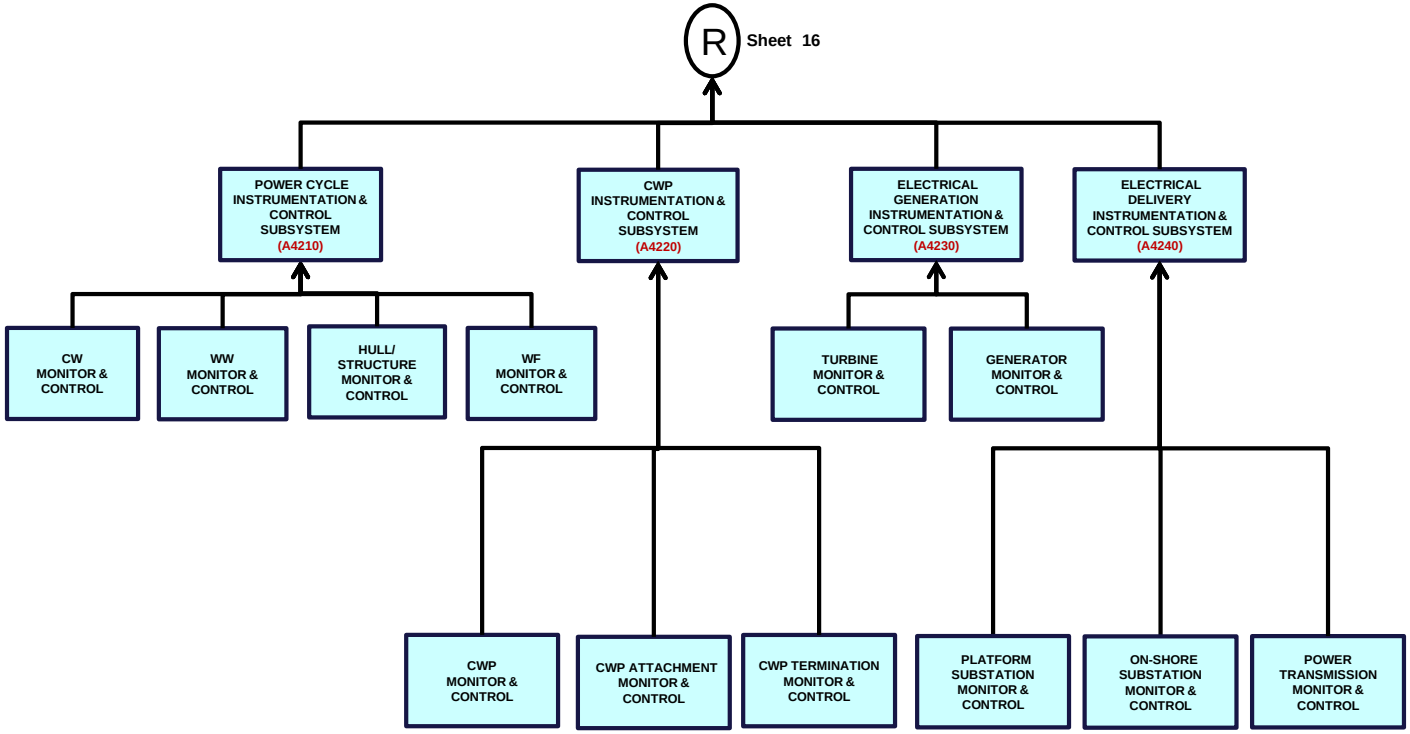


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OTEC Pilot Plant Physical Architecture

Power (Cycle) Management Element

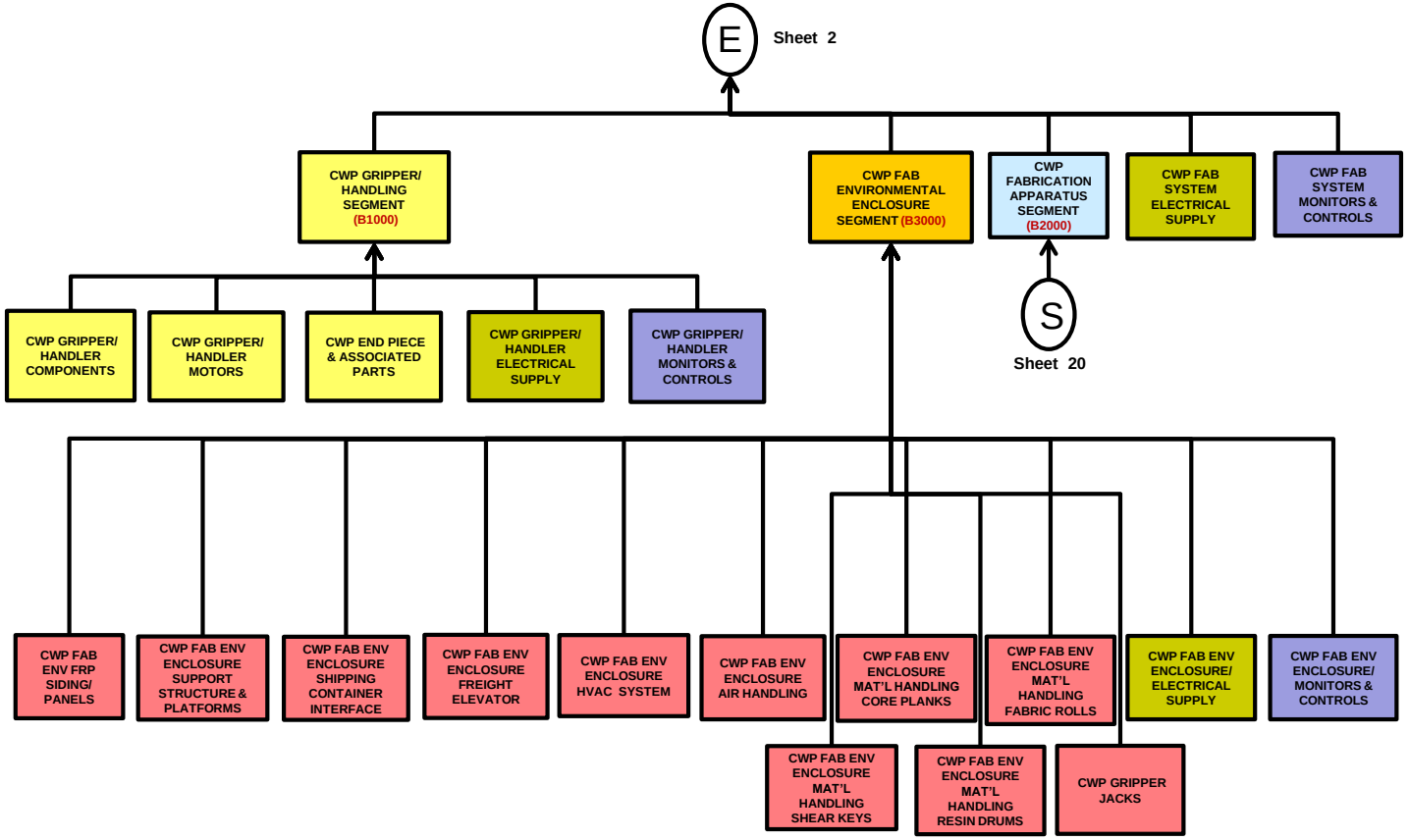
Integrated Instrumentation & Control Segment



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OTEC Pilot Plant Physical Architecture

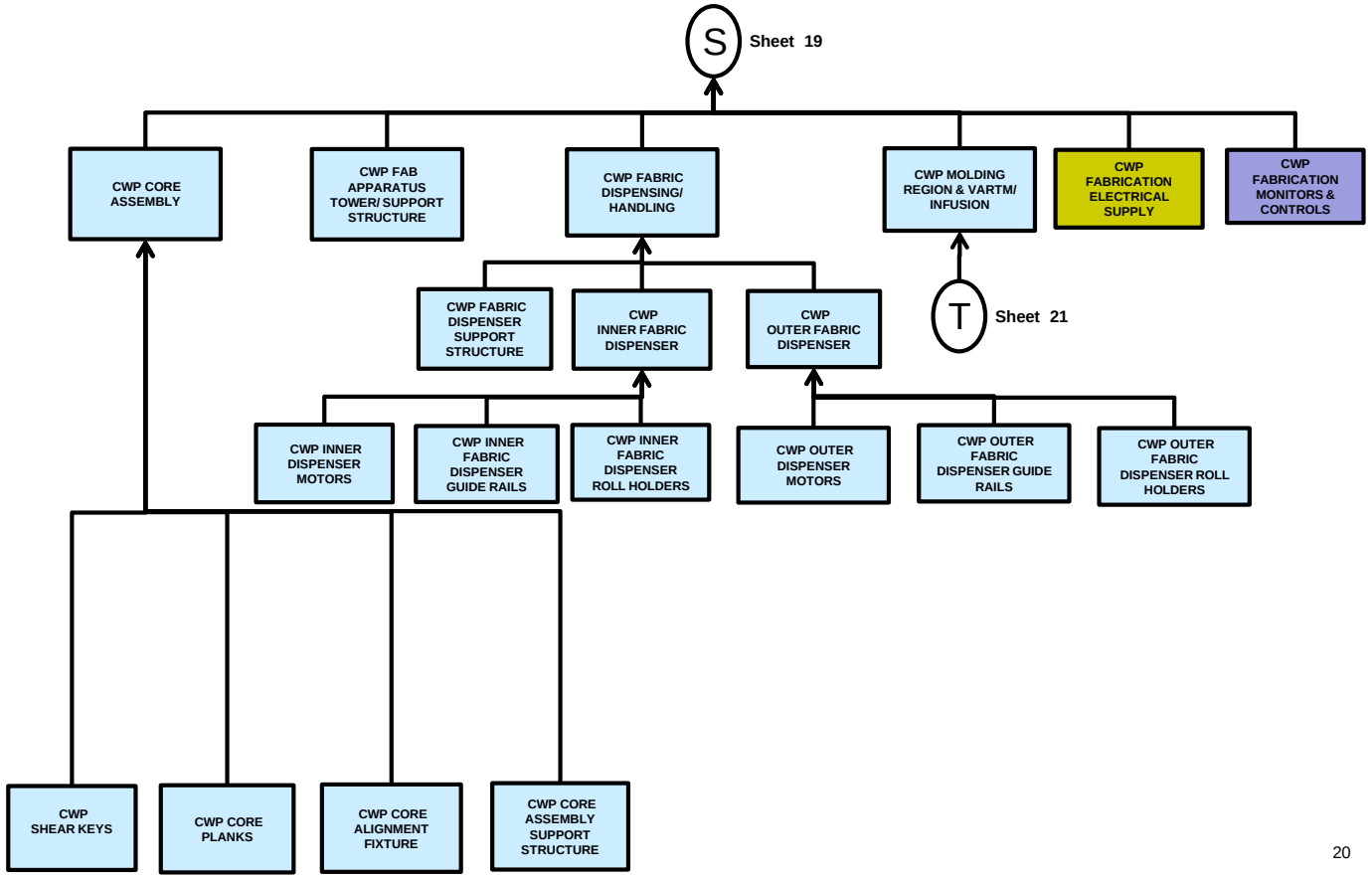
CWP Fabrication System



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OTEC Pilot Plant Physical Architecture

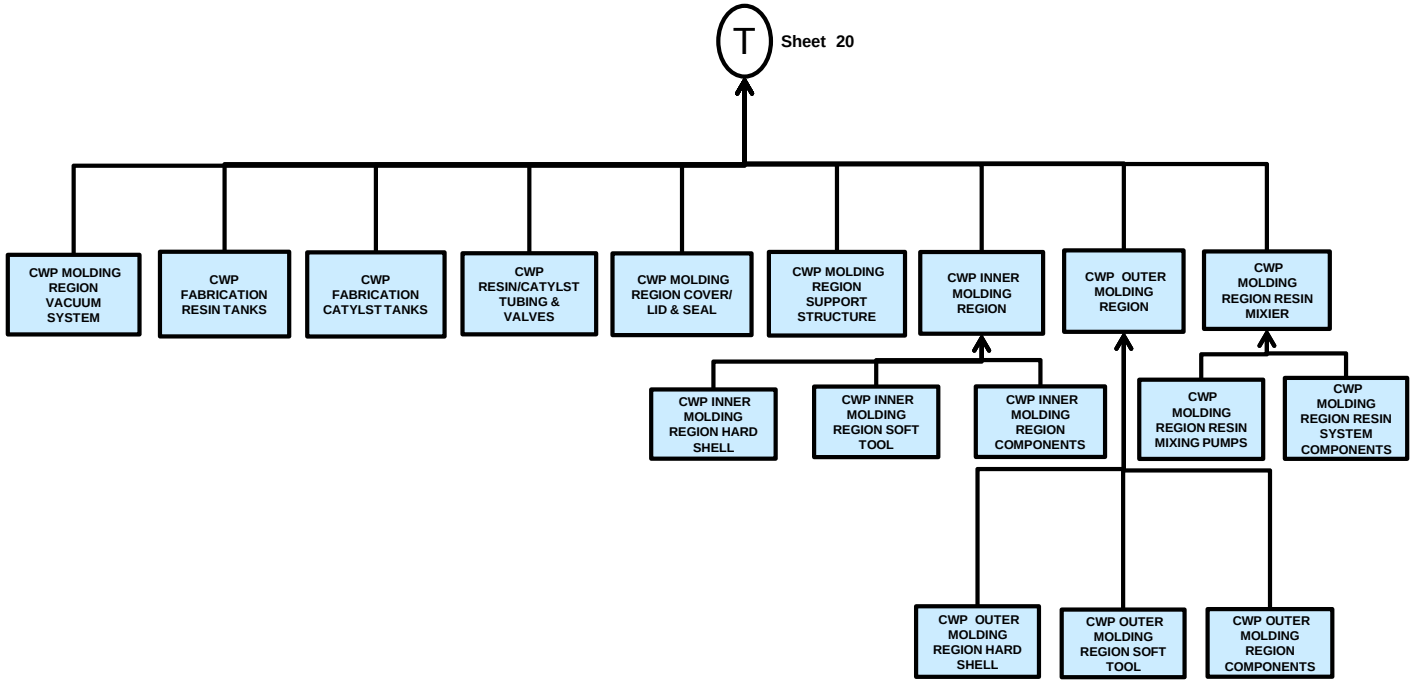
CWP Fabrication Apparatus - CWP Fabrication System



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OTEC Pilot Plant Physical Architecture

CWP Fabrication Apparatus - CWP Fabrication System



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NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 4.1-2
OTEC Pilot Plant System Integration Test Plan Draft
OTEC-2010-001

17 September 2010

Prepared for:

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DRAFT
Test Plan

for the

OTEC Pilot Plant

System Integration & Test (SI&T)

Number of Pages: 139

Contract No. N62583-09-C-0083
Customer: US Naval Facilities Command (NAVFAC)

Plan Revision: Draft

Plan Revision Date: 29 June 2010

Prepared by:
Lockheed Martin MS2

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APPROVAL PAGE

DRAFT
Test Plan
for the
OTEC Pilot Plant
System Integration & Test (SI&T)

Rev New

21 May 2010

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REVISION RECORD

Revision	Date	Description of & Reason for Changes
Draft	29 June 2010	Initial Release
New		
A		
B		
C		

ABSTRACT/FOREWORD

This Test Plan describes the System Integration and Test activities for the OTEC Pilot Plant. These activities will occur in three phases. The first at the Platform builder's facility, the second Quay-side in Hawaii and the Third at sea once the platform is located to the selected site.

The first phase will consist of installing and checking out the facilities and equipment …. Installing the topsides spaces and equipment (e.g. Turbine-Generators, Ammonia Storage, etc.),

The second phase will consist of installing and integrating …. Including the CWP Fabrication Env Enclosure and apparatus, the Integrated Instrumentation and Control Segment,

The third phase will consist of locating the platform at the selected site, installing the sea keeping subsystems, installing, connecting and operating the Remora Element, and fabricating and deploying the Cold Water Pipe, CW ducting.

Integration and Testing (I&T) prior to this SI&T series will have been conducted at the installing activities' site for the Platform Segment, and at Land Based Test Sites (LBTS) for the Remora and Integrated I&C Segments. Separate Test Plans cover these activities.

The CWP Fabrication System will have been tested at an LBTS, Quay-side, and At Sea which will include production of several hundred feet of Cold Water Pipe. Separate Test Plans cover these activities.

After completion of this SI&T the Pilot Plant will be operated for a period of about two years to undergo various system measurements and evaluations. A separate Test Plan covers these activities.

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1.0 INTRODUCTION

This OTEC Pilot Plant System Integration & Test (SI&T) Plan documents the test requirements, objectives, events, and test configurations for conducting the OTEC Pilot Plant System Integration &Test (SI&T) event.

These activities are planned to be conducted in three phases. The first at the Platform builder's facility, the second Quay-side in Hawaii and the third at sea once the platform is relocated to the selected operating site.

The first phase will consist of installing and checking out the Platform structure and the facilities and equipment installed on the Platform Topsides and Hull (e.g. Turbine-Generators, Ammonia Storage, Integrated I&C, foundations and fixtures for Controls center, Helo landing, emergency systems, communications, Remoras, Sea keeping, etc.). Refer to Appendix D-1 for the configuration diagrams for this test.

The second phase will consist of installing and integrating newly introduced items such as the CWP Fabrication System (Apparatus and Environmental Enclosure), the Integrated Instrumentation and Control Segment, and Remora horizontal attitude testing. Refer to Appendix D-2 for the configuration diagrams for this test.

The third phase will consist of locating the platform at the selected site, installing the sea keeping subsystems, installing, connecting and operating the Remora Element, and fabricating and deploying the Cold Water Pipe, and CW crossover ducting. Refer to Appendix D-3 for the configuration diagrams for this test.

Integration and Testing (I&T) prior to this SI&T series will have been conducted at the installing activities' site for the Platform Segment, and at Land Based Test Sites (LBTS) for the Remora and Integrated I&C Segments. Separate Test Plans cover these activities.

The CWP Fabrication System will have been tested at a LBTS, Quay-side, and At Sea including production of several hundred feet of CWP. Separate Test Plans cover these activities.

After completion of this SI&T the Pilot Plant will be operated for a period of approximately two years to undergo performance measurement and evaluation. A separate Test Plan will cover these activities.

The schedule of test activities is provided as Appendix B.

1.1 Purpose of the Test

The purpose of this SI&T is to integrate and functionally test the hardware (electrical and mechanical) and software (or firmware) incorporated into the OTEC Pilot Plant in phases. For the purposes of this Test Plan the OTEC Pilot Plant System is defined as and is comprised of the following:

OTEC System

- **Platform Segment** (Topsides, Hull, Station keeping, Electrical Plant, Communication and Control, Auxiliary and Outfit & Furnishing Elements)
- **Power Generation Segment** (Power Cycle [Remora(s)], Cold Water Pipe and Electrical Generation [Turbine-Generator] Elements)

- **Power Delivery Segment**/Element (Platform Substation, Power Transmission, and On-shore Substation Elements)
- **Integrated Instrumentation and Control Segment** (Command, Control, and Communication) System

OTEC Cold Water Pipe (CWP) Fabrication System

- **Gripper/Handler Segment** (TBS Elements)
- **Fabrication Apparatus** (Core Assembly, Fabric Dispensing & Placement, Molding/VTRM Elements, and Tower/supporting structure)
- **Environmental Enclosure** (Support Structure, Panels, Material Handling and HVAC elements/systems)

1.2 Test Objectives

The Overall (Primary) objective of this SI&T is to verify that the OTEC Pilot Plant System meets the requirements specified in the OTEC Pilot Plant System Specification, Segment Specifications, Segment Interface Requirements and Acceptance Test Requirements/Specification. The following paragraphs are the specific test objectives (Secondary) of this SI&T:

- Verify the interoperability and compatibility of the OTEC Pilot Plant Segments (Platform, Power Generation, Power Delivery, Integrated Instrumentation Control), and the CWP Fabrication System.
- Verify proper OTEC Pilot Plant operation under abnormal conditions including causality configurations.
- Verify proper operation of System Safety provisions including hazardous conditions.
- Verify the operation of the System Built-In-Test-Equipment (BITE) and Built-In-Test (BIT) fault detection and reporting functions.
- Verify the data collection, data extraction/reduction, and fault condition reporting functions of the Integrated Instrumentation and Control System.

1.3 Scope of Testing

The SI&T will be conducted with a standard set of tests to verify the OTEC Pilot Plant at the system level. Additional tests, such as fault tests, will be used to ensure a comprehensive approach to the verification process.

Outstanding/Open System Trouble Reports are listed in Appendix E. These Trouble Reports document "known" anomalies that could be observed during the test event.

This SI&T will be divided into the following events and parts:

Phase 1 – Platform Builder's (Installing Activity) Facility

Event 1: Component and Subsystem Installation (Mounting and Connecting)

Part 1: Platform (Hull & Topsides)

A. Electrical Plant
B. Communication & Controls
C. Auxiliary Systems

D. Outfit & Furnishings
E. Sea keeping [Platform Interfaces only]

Part 2: Power Generation

A. Power Cycle (Remora) [Platform Interfaces only]
B. Cold Water Pipe [Platform/Hull Interfaces only]
C. Electrical [Turbine-Generator Set, cabling, and support systems]

Part 3: Power Delivery

A. Platform Substation (Switchgear, transformers, batteries, SCADA, and control and power cabling)
B. Power Transmission (Cabling, Connections, Vault) [Platform Interfaces only]
C. Onshore Substation (Switchgear, transformers, batteries, SCADA, and control and power cabling) [occurs at selected site location]

Part 4: Integrated I&C

A. Platform Management (Platform, Safety, Security and Communications)
B. Power (Cycle) Management (Power Cycle, Cold Water Pipe, Electrical Generation, Electrical Delivery)
C. Environmental Monitoring Management (TBS)

Event 2: Component and Subsystem Light-off

Part 1: Platform (Hull & Topsides; Station keeping is N/A for this test)

A. Electrical Plant (TBS)
B. Communications (Interior and Exterior)
C. Controls (TBS)
D. Auxiliaries (TBS)
E. Outfit & Furnishings (TBS)

Part 2: Power Generation (Electrical Delivery; Power Cycle and CWP are N/A for this test)

A. Turbine-Generator Set
B. Turbine-Generator Support equipment (TBS)

Part 3: Power Delivery

A. Platform Substation (TBS)
B. Onshore Substation (TBS) [occurs at selected site location]
C. Power Transmission (N/A for this test)

Part 4: Integrated I&C

A. Platform Management (Platform, Safety, Security and Communications)
B. Power (Cycle) Management (Power Cycle, Cold Water Pipe, Electrical Generation, Electrical Delivery)
C. Environmental Monitoring Management (TBS)

Event 3: Element Integration and Test

Part 1: Platform

A. Topsides (except Platform Substation?)

B. Hull
C. Station keeping (N/A for this test)

Part 2: Power Generation

A. Power Cycle (N/A for this test)
B. CWP (N/A for this test)
C. Electrical Generation

Part 3: Power Delivery (Electrical Delivery)

A. Platform Substation
B. Onshore Substation [occurs at selected site location]
C. Power Transmission (N/A for this test)

Part 4: Integrated I&C

A. Platform Management
B. Power (Cycle) Management
C. Environmental Monitoring Management

Event 4: Segment Integration and Test

Part 1: Platform (Hull & Topsides; Station keeping is N/A for this test)

Part 2: Power Generation (Electrical Generation; Power cycle and CWP are N/A for this test)

Part 3: Power Delivery (Platform and On-Shore Substations; Power Transmission Cabling is N/A for this test)

Part 4: Integrated I&C

Event 5: System Integration and Test (Limited)

Part 1: Start-Up

A. Initial Conditions
B. Initial Indications (Light-off)
C. TBS

Part 2: Normal Operation

A. Full Capacity
B. Reduced Capacity
C. No Load

Part 3: Casualty Operations

A. Cold Water Pump Fault
B. Warm Water Pump Fault
C. Working Fluid Pump Fault
D. Electrical System Fault
E. HVAC System Fault
F. II&C System Faults

G. Turbine Fault
H. Generator Fault
I. Mooring/Station keeping Fault
J. Platform Stabilization Fault
K. TBS Fault
L. TBS

Part 4: Safety Hazards

A. Fire
B. Smoke
C. Flooding
D. Collision
E. Abandon Ship
F. Ammonia Leak
G. Storm
H. Intrusion
I. Flight Operations
J. Resin Spill
K. TBS

Part 5: Shut-Down

A. Emergency Shut-down
B. Normal Off-line
C. Cold Iron Power-down

Phase 2 – Quay-Side Installation and Check-out (INCO) (Oahu, Hawaii)

Event 1: Component and Subsystem Installation (Mounting and Connecting)

Part 1: Cold Water Pipe Fabrication System

A. Topside Equipment (Enclosure and Apparatus)
B. Hull Equipment (Gripper/Handler and CWP Interface/Mounting)

Event 2: Component and Subsystem Light-off

Part 1: CWP Environmental Enclosure

A. Electrical (TBS)
B. HVAC (TBS)
C. Material Handling (Core Planks & Shear Keys, Fabric Rolls, Resin)
D. Vacuum Supply System
E. Compressed Air Supply System
F. Safety Systems (TBS)

Part 2: CWP Fabrication Apparatus

A. Tower/Support Structure
B. Core Assembly Region
C. Fabric Distribution Region
D. Molding/VTRM Region
E. Safety Systems (TBS)

Part 3: CWP Gripper/Handler

A. Gripper (TBS)
B. Handler (TBS)
C. Guides (TBS)
D. Safety Systems (TBS)

Part 4: Integrated I&C

A. Cold Water Pipe
B. CWP Fabrication System

Part 5: Remora in Horizontal Orientation (not installed; floating)

A. Connections to Turbine-Generator Set
B. Connections to CW source
C. Connections to WW source
D. Connections to Electrical source
E. Connections to WF/Ammonia source
F. Connections to II&C system

Event 3: Element/Segment Integration and Test

Part 1: CWP Fabrication System

Part 2: Integrated I&C

A. Cold Water Pipe (Fab System)
B. Environmental (TBS)
C. Safety, Security, and Communications (TBS)

Part 3: Remora in Horizontal Orientation (not installed; floating)

A. Turbine-Generator Element
B. CW Subsystem/path
C. WW Subsystem/path
D. Ammonia Subsystem/path
E. Electrical Subsystem
F. Controls Subsystems

Event 4: System Integration and Test (Partial)

Part 1: Start-Up

A. Initial Conditions
B. Initial Indications (Light-off)
C. Steady State

Part 2: Normal Operation

D. Full Capacity
E. Reduced Capacity
F. No Load

Part 3: Casualty Operations

A. Cold Water Pump Fault
B. Warm Water Pump Fault
C. Working Fluid Pump Fault
D. Electrical System Fault
E. HVAC System Fault
F. II&C System Faults
G. Turbine Fault
H. Generator Fault
I. Mooring/Station keeping Fault
J. Platform Stabilization Fault
K. TBS Fault
L. TBS

Part 4: Safety Hazards

A. Fire
B. Smoke
C. Flooding
D. Collision
E. Abandon Ship
F. Ammonia Leak
G. Storm
H. Intrusion
I. Flight Operations
J. Resin Spill
K. TBS

Part 5: Shut-Down

A. Emergency Shut-down
B. Normal Off-line
C. Cold Iron Power-down

Phase 3 – At Sea Installation and Check-out (INCO) (Deployed in Oahu, Hawaii)

Event 1: Component and Subsystem Installation (Mounting and Connecting)

Part 1: Platform Sea keeping Subsystems

A. Tensioning
B. Tension Members
C. Seafloor Anchors

Part 2: Power Generation - Cold Water Pipe Element (Fabrication and Deployment)

A. Pipe and Instrumentation
B. Termination
C. Platform Attachment/Mounting
D. Crossover Ducting Installation & Test
E. II&C Connections

Part 3: Power Generation - Power Cycle (Remora) Element

A. Remora Upending & Attachment
B. Remora Electrical System Connections (to Electrical Power System)
C. Remora Ammonia System Connections (to Turbine and Charging Station)
D. Remora Integrated I&C Connections (Safety, Environmental, Performance Control, etc.)
E. Cold Water Ducting Connection (to CWP)
F. II&C Connections

Part 4: Power Delivery Element

A. Subsea Power Transmission Cabling/Connections
B. Power Cable Vault/Landfall
C. Land Power Transmission Cabling/Connections
D. II&C Connections

Part 5: Integrated I&C

A. Platform (for any new items)
B. Power Cycle (Remora Interfaces)
C. Cold Water Pipe
D. Electrical Generation (for any new items)
E. Electrical Delivery (Power Cabling and On-shore Substation Interfaces)
F. Environmental (for any new items)
G. Safety, Security and Communications (for any new items)

Event 2: Component and Subsystem Light-off

Part 1: Platform

A. Electrical Plant (for any new items)
B. Communication (for any new items)
C. Controls (for any new items)
D. Auxiliary Systems (for any new items)
E. Outfit & Furnishing (for any new items)

F. Station keeping systems (Tensioning, Tension Members, and Seafloor Anchors)

Part 2: Power Generation

A. Remora Electrical System
B. Remora Ammonia System (including Fill/Charging Station)
C. Remora Integrated I&C

Part 3: Power Delivery

A. Subsea Power Transmission Cabling/Connections Tests
B. Land Power Transmission Cabling/Connections Tests
C. Platform Substation Tests (any new items)
D. Onshore Substation Tests (any new items)

Part 4: Integrated I&C

A. Platform (for any new items)
B. Power Cycle (Remora)
C. Cold Water Pipe
D. Electrical Generation (for any new items)
E. Electrical Delivery (Power Cabling, On-shore Substation)
F. Environmental (for any new items)
G. Safety, Security, and Communications (for any new items)

Event 3: Element Integration and Test

Part 1: Platform

A. Electrical Plant (for any new items)
B. Communication & Controls (for any new items)
C. Auxiliary Systems (for any new items)
D. Outfit & Furnishings (for any new items)
E. Station keeping dynamic testing

Part 2: Power Generation

A. Remora to Turbine-Generator Set
B. Remora to CWP

Part 3: Power Delivery

A. Subsea Power Cabling to Land Power Cabling
B. Platform Substation to Power Cabling Connection Tests
C. On-shore Substation to Power Cabling Connection Tests

Part 4: Integrated I&C

A. Platform Management - Safety, Security, and Communications
B. Platform Management (for any new items)
C. Power Management - Power Cycle
D. Power Management - Cold Water Pipe
E. Power Management - Electrical Generation
F. Power Management - Electrical Delivery

G. Environmental Management (any new items)

Event 4: Segment Integration and Test

Part 1: Platform to Power Generation (Remora, CWP, and Turbine-Generator)

Part 2: Platform to Power Delivery (Platform Substation, Transmission Cabling, and On-Shore Substation)

Part 3: Platform to Integrated I&C

Part 4: Platform (Hull & Topsides) to CWP Fabrication System

Part 5: Power Generation to Power Delivery

Part 6: Power Generation to Integrated I&C

Part 7: Power Delivery to Integrated I&C

Part 8: Integrated I&C to all Components, Subsystems, and Elements

Event 5: System Integration and Test

Part 1: Start-Up

This test event will consist of a series of steps necessary to bring the system to an operational state.

A. Initial Conditions

B. Initial Indications (Light-off)

C. TBS

Part 2: Normal Operation

This test event will consist of a series of no fault system tests including ***TBD***. This test event will consist of a series of steps necessary to bring the system to a Standby/Ready state.

A. Full Capacity

B. Reduced Capacity

C. No Load

Part 3: Casualty Operations

This test event will consist of a series of fault system tests including ***TBD*** to verify the Built-In Test Equipment (BITE) capabilities of the OTEC Pilot Plant. Tests will verify the OTEC Pilot Plant Integrated I&C System fault detection, reporting, and control capabilities. This test series will verify the ability of the OTEC Pilot Plant to detect, process, and react to fault-induced sequences at various points in the operational sequence.

A. Cold Water Pump Fault

B. Warm Water Pump Fault

C. Working Fluid Pump Fault

D. Electrical System Fault

E. HVAC System Fault

F. II&C System Faults

G. Turbine Fault

H. Generator Fault

I. Mooring/Station keeping Fault

J. Platform Stabilization Fault

K. TBS Fault

L. TBS

Part 4: Safety Hazards

This test event will verify the system safety features of the OTEC Pilot Plant. Hazard monitoring and Failure reporting will be verified in the ***TBD*** operating modes. Tests will verify the OTEC Pilot Plant Integrated I&C System fault detection, reporting, and control capabilities for Hazardous conditions. This test series will verify the ability of the OTEC Pilot Plant to detect, process, and react to fault-induced sequences at various points in the operational sequence.

A. Fire

B. Smoke

C. Flooding

D. Collision

E. Abandon Ship

F. Ammonia Leak

G. Storm

H. Intrusion

I. Flight Operations

J. Resin Spill

K. TBS

Part 5: Shut-Down

This test event will consist of a series of steps necessary to bring the system to an Off state.

A. Emergency Shut-down

B. Normal Off-line

C. Cold Iron Power-down

Event 6: Cold Water Pipe Fabrication Apparatus Removal

Part 1: Environmental Enclosure

Part 2: Fabrication Apparatus

Part 3: Gripper/Handler

1.4 Limitations to Scope

This SI&T is limited to testing of the OTEC Pilot Plant System itself and does not include the interfacing of the PP System with the Electrical Power Grid System. It also does not include

Operational Test & Evaluation to be performed during the "pilot" phase once the system has been deployed and is operational. These tests are covered in separate Test Plans.

The SI&T is a test event that integrates the hardware and software elements that make up the OTEC Pilot Plant at the system level. This will occur in three stages, and will not involve all parts of the System until the final At Sea INCO. Due to the nature of system level testing the following assumptions and constraints apply:

- Some system requirements cannot be tested using the system level test configuration. These requirements are tested at lower-level events, such as TBD, using firmware and/or software modified for specific test purposes. Refer to Appendix C for the RVTM Index for this SI&T. Refer to the Project RVTM for a complete listing of System/Test requirements and their associated Verification method.
- Tests may be conducted out of sequence as long as they are documented as such.
- Tests may be restructured in order to obtain more detailed test data and will be so documented.
- Special instrumentation may be added as deemed necessary to achieve specific test objectives.
- Tests may be added to better satisfy system test objectives.
- Tests may be deleted as long as they have been conducted under another documented test procedure and test data are available.
- All deviations will be annotated in the SI & Test Procedures documented in the SI & Test Report.

1.5 Security Requirements

TBD.

2.0 REFERENCE DOCUMENTS

The following documents of the exact issue shown form a part of this document to the extent specified herein.

2.1 Standards

2.1.1 ANSI

2.1.2 DoE

2.1.3 DoD

2.1.4 EPA

2.1.5 NOAA

2.1.6 TBS

2.2 Vessel/Ship Specifications

2.2.1 American Bureau of Shipping (ABS)

2.2.2 Coast Guard

2.2.3 TBS

2.3 Contractor Specifications and Plans

2.3.1 OTEC Pilot Plant Top Level Requirements

2.3.2 OTEC Pilot Plant System Specification/Requirements

2.3.3 OTEC Pilot Plant Platform Segment Requirements

2.3.4 OTEC Pilot Plant Platform Design Basis

2.3.5 OTEC Pilot Plant Power Generation Segment Requirements

2.3.6 OTEC Pilot Plant Power Delivery Segment Requirements

2.3.7 OTEC Pilot Plant Integrated Instrumentation & Control Segment Requirements

2.3.8 OTEC Pilot Plant Cold Water Pipe Fabrication System Requirements

2.3.9 OTEC Pilot Plant Cold Water Pipe Fabrication System Design Basis

2.3.10 OTEC Pilot Plant CONOPS for Operations

2.3.11 OTEC Pilot Plant CONOPS for Installation & Deployment (INCO)

2.3.12 OTEC Pilot Plant Operational Scenarios

2.3.13 OTEC Pilot Plant Element Specifications

2.3.14 OTEC Pilot Plant Subsystem Specifications

2.3.15 OTEC Pilot Plant Component/Assembly Specifications

2.3.16 OTEC Pilot Plant Master Test Plan

2.3.17 OTEC Pilot Plant RVTM (SRVM)

2.4 Drawings – Customer

2.4.1 OTEC Pilot Plant Platform Segment General Arrangement Drawings

2.4.2 OTEC Pilot Plant Power Generation Segment Drawings

2.4.3 OTEC Pilot Plant Power Delivery Segment Drawings

2.4.4 OTEC Pilot Plant Integrated Instrumentation & Control Segment Drawings

2.4.5 OTEC Pilot Plant Cold Water Pipe Fabrication System Drawings

2.5 Manuals

2.5.1 TBD

2.6 Other

2.6.1 TBS

3.0 SYSTEM DESCRIPTION/OVERVIEW

3.1 System/System Hardware

The following paragraphs provide an overview of the various test articles that will form a part of the SI&T test configuration. The exact equipment configuration that will be used for SI&T is contained in Appendix D.

3.1.1 Platform Segment

The Platform Segment serves as the "vessel" for the OTEC Pilot Plant containing all of the necessary equipment and features for the Pilot Plant. The Platform Segment consists of the following Elements:

3.1.1.1 Topsides Element

The Topside Element contains the deck structures that house the major segments of the Pilot Plant including the Remora(s), CWP and delivery components, Turbine-Generator(s), Electrical conditioning and distribution/delivery, Integrated Instrumentation & Controls, and all human occupation and safety support services and systems.

3.1.1.2 Hull Element

The Hull Element contains the major structural components that support the Topsides Element and keeps the platform afloat and stationary. The Hull Element consists of Columnar structures supports/trusses/braces, pontoon structure, and keel.

3.1.1.3 Sea Keeping Element

The Sea keeping Element the keeps the platform stable and stationary consisting of Tensioning, Tension members, and Seafloor Anchor Subsystems.

3.1.2 Power Generation Segment

The Power Generation Segment is the "heart" of the OTEC Pilot Plant which produces electrical energy using a closed loop Rankin cycle. The Power Generation Segment consists of the following Elements:

3.1.2.1 Power Cycle Element (Remora)

The Power Cycle Element contains the heat exchangers and working fluid subsystems that process the cold and warm seawater with the working fluid to produce "stream" to drive the turbine. The Power Cycle Element consists of a hull/structure, condenser, evaporator, and ammonia subsystems as well as seawater intake, discharge, pumping, corrosion, and bio-fouling control components.

3.1.2.2 Cold Water Pipe Element

The CWP delivers cold seawater to the Pilot Plant from a depth of approximately 1000 meters. The pipe is approximately 10 meters in diameter and is fabricated in-situ using composite materials. Historically, the CWP has presented the greatest challenge to OTEC power plants. The CWP consists of the pipe itself, a transition or termination structure and an attachment/gimbal structure.

3.1.2.3 Electrical Generation Element

The Electrical Generation Element processes the ammonia vapor/"steam" through the turbine which operates the generator producing electrical power. The Electrical Generation Element consists of the Turbine-Generator Set and associated support equipment.

3.1.3 Power Delivery Segment/Element

The Power Delivery Segment/Element provides the capability to deploy the electrical energy produced by the Pilot Plant for operating the Pilot Plant as well as to supply electrical power to a local service grid. The Power Delivery Element consists of the following Subsystems:

3.1.3.1 Platform Substation Subsystem

The Platform Substation Subsystem consists of Switchgear, transformers, power cabling, control cabling, SCADA equipment, and batteries to prepare and condition the electrical power for transmission to the On-Shore Substation.

3.1.3.2 Power Transmission Subsystem

The Power Transmission subsystem consists of undersea cabling, a shore landing vault and overland cabling.

3.1.3.3 On-shore Substation Subsystem

The On-Shore Substation Subsystem consists of Switchgear, transformers, power cabling, control cabling, SCADA equipment, and batteries to prepare and condition the transmitted electrical power for entry into the local power grid.

3.1.4 Integrated Instrumentation and Control Segment

The Integrated Instrumentation and Control (II&C) Segment is the "brain" and central control station for all monitoring, data gathering, statusing, surveillance and control operations for the Pilot Plant. A central control station will house the electronic console/work station, computers and computer controlled measurement, recording, and display equipment. The II&C Segment consists of the following elements:

3.1.4.1 Platform Management I&C Element

The Platform Management Element provides monitoring and control for the Topsides, Hull, and Sea keeping Subsystems.

3.1.4.2 Power (Cycle) Management I&C Element

The Power Management Element provides monitoring and control for the Power Cycle (Remora) and Safety, Security & Communications Subsystems.

3.1.4.3 Environmental Monitoring Management I&C Element

The Environmental Monitoring Management Element consists of TBS.

3.1.5 Cold Water Pipe Fabrication System

The CWP Fabrication System is a temporary structure necessary when manufacturing the Cole Water Pipe. It is removed once the CWP is built and successfully deployed. The CWP Fabrication System consists of the following Segments:

3.1.5.1 Fabrication Apparatus Segment

The CWP Fabrication Apparatus consists of a Tower (support Structure), Core Assembly Region, Fabric Placement/Dispensing Region and a Molding Region.

3.1.5.2 Environmental Enclosure Segment

The CWP Fabrication Environmental Enclosure consists of a superstructure, panels, material handling systems and HVAC/electrical system.

3.1.5.3 Gripper/Handler Segment

The Gripper/H consists of a Gripper/Handler assembly (fixed and movable grippers), Guide Assembly (fixed), and electronic motors, actuators and controls.

3.2 Computer Programs/Software

The following paragraphs provide an overview of the various computer programs that will form a part of the SI&T test configuration. The exact program version/configuration that will be used for SI&T is contained in Appendix E.

3.2.1 Integrated Instrumentation and Control Software Program

The II&C Software/Computer Program integrates the processing of the Platform Management and OTEC software applications packages.

3.2.2 Platform Management System Software Program

The Platform Management software application provides monitoring and control of all standard non-OTEC components and subsystems. These include all Topsides, Hull and Station keeping elements, subsystems, assemblies, and components.

3.2.3 Power Generation Management System Software Program

The Power Generation Management software application provides monitoring and control of all OTEC Power Cycle (Remora), Cold Water Pipe, and Electrical Generation elements, subsystems, assemblies, and components.

3.2.4 Power Delivery Management System Software Program

The Power Delivery Management software application provides monitoring and control of all OTEC Electrical Delivery element subsystems, assemblies, and components. These include the Platform Substation, On-shore Substation, and Power transmission cabling and equipment.

3.2.5 Environmental Monitoring Management Software Program

The OTEC Environmental Monitoring Management software applications provide monitoring and control of all OTEC specific Environmental Monitoring element subsystems, assemblies, and components. These include TBS.

4.0 PRODUCT/SYSTEM INTEGRATION ENVIRONMENT

This SI&T will be conducted in three phases at three different sites; at the Shipyard, Quay-side in HI and "at sea" at the Pilot Plant site near Pearl Harbor Oahu, HI.

During the conduct of this test, particular/peculiar OTEC test equipment will be used to simulate/stimulate the portions of the system that are not being tested, record system responses, insert system faults, and provide monitoring and measurements of timing, voltage & current levels, position, temperature, pressure, vibration, shock, and signal levels and waveforms. All test equipment, including applicable standard test tools and OTEC unique/special equipment, shall be calibrated and have calibration stickers that are valid for the duration of the test period.

4.1 Test Facility/Site

Phase 1 will be conducted at a Shipyard or similar facility where the OTEC Pilot Plant Platform will be constructed.

Phase 2 will be conducted Quay-side in Hawaii.

Phase 3 will be conducted "At Sea" on the selected site near Pearl Harbor Oahu, HI.

4.2 Special Test Equipment

In addition to standard Marine Systems INCO test tools and equipment the following special test tools and equipment will be required:

4.2.1 Power Cycle (Remora) Simulator

The Power Cycle (Remora) Simulator is used for Turbine-Generator testing.

4.2.2 Electrical Generation (Turbine-Generator) Simulator

The Electrical Generation (Turbine-Generator) Simulator is used for Remora and Platform Substation testing.

4.2.3 Platform Substation Simulator

The Platform Substation Simulator is used for Power Transmission cable and Electrical Generation (Turbine-Generator) testing.

4.2.4 Power Transmission Cable Simulator

The Power Transmission Cable Simulator is used for On-Shore and Platform Substation testing.

4.2.5 On-Shore Substation Simulator

The On-Shore Substation Simulator is used for Power Transmission cable testing.

4.2.6 Local Grid Simulator

The Local Grid Simulator is used for OTEC system and On-Shore Substation testing.

4.2.7 Integrated I&C Segment Simulator

The Integrated I&C Segment Simulator is used for II&C Segment Software testing.

4.2.8 Platform Management I&C Simulator

The Platform Management I&C Simulator is used for Platform Sensor & Software and II&C Segment testing.

4.2.9 Power Cycle I&C Simulator

The Power Cycle I&C Simulator is used for Power Cycle and II&C Segment testing.

4.2.10 CWP I&C Simulator

The CWP I&C Simulator is used for CWP Sensor & Software and II&C Segment testing.

4.2.11 Electrical Generation I&C Simulator

The Electrical Generation I&C Simulator is used for Electrical Generation Sensor & Software and II&C Segment testing.

4.2.12 Electrical Delivery I&C Simulator

The Electrical Delivery I&C Simulator is used for Electrical Delivery Sensor & Software and II&C Segment testing.

4.2.13 Environmental Monitoring Management I&C Simulator

The Environmental Monitoring Management I&C Simulator is used for Environmental Monitoring Management Sensor & Software and II&C Segment testing.

4.2.14 Environmental Data Acquisition System (EDAS)

The Environmental Data Acquisition System (EDAS) is used for environmental data collection.

4.2.15 Event Data Acquisition System (DAS)

The Event Data Acquisition System (DAS) is used for message traffic content recording & timing and general data collection and processing.

4.2.16 Remora to Turbine-Generator Horizontal Test Piping

The Remora to Turbine-Generator Horizontal Test Piping is used for temporarily connecting the Remora ammonia subsystem to the Turbine-Generator during Quay-Side checkout.

4.2.17 Remora Horizontal Test Cabling (Signal & Electrical Power)

The Remora Horizontal Test Cabling is used for temporarily connecting the Remora electrical and signal monitoring & control subsystems to electrical service and the II&C Segment.

4.2.18 Piping Hydro Test Kit

The Piping Hydro Test Kit is used to perform hydrostatic testing of seawater and ammonia subsystem piping, ducting, and valves.

4.2.19 Dummy load

The Dummy load is used for Turbine-Generator testing.

5.0 TEST PREPARATION AND PARTICIPATING AGENCIES

5.1 Test Preparation/Prerequisites

The following tests/activities are a prerequisite to the start of the OTEC Pilot Plant SI&T events:

5.1.1 Phase 1 Shipyard Activities

Completion of the OTEC Pilot Plant Assembly, Component and Subsystem Integration & Test and Acceptance/Qualification activities and delivery of each to the site. This consists of the following:

- Completion, to the extent necessary and specified, of the Platform Segment Construction, Testing, and Acceptance.
- Completion of the Electrical Generation Turbine-Generator Subsystems Factory Acceptance Tests.
- Completion of the Integrated Instrumentation and Control Element/Segment Factory Acceptance Tests.
- Completion of the Warm Water Handling System Factory Acceptance Tests.
- Completion of the Cold Water Handling System Factory Acceptance Tests.
- Completion of the Ammonia Handling System Factory Acceptance Tests.
- Completion of the Cold Water Pipe Design Analysis and Acceptance Tests.
- Completion of the Cold Water Pipe Fabrication System Acceptance Test.
- Completion of OTEC Pilot Plant System Shipyard Test Readiness Review (TRR).

5.1.2 Phase 2 Quay-Side Activities

Completion of the OTEC Pilot Plant Shipyard Subsystem and Element Integration & Test and Acceptance/Qualification activities and delivery/receipt of equipments at the site. This consists of the following:

- Completion of the Platform Segment Acceptance Testing (less Sea Keeping).
- Completion of the Power Cycle (Remora) Element Factory Acceptance Tests.
- Completion of the Electrical Generation Turbine-Generator Element/Segment Acceptance Tests.
- Completion of the Integrated Instrumentation and Control Segment Acceptance Tests.
- Completion of the On-Shore Substation Subsystems Acceptance Tests.
- Completion of the Station Keeping Subsystems Factory Acceptance Tests.
- Completion of the Power Transmission Cable Subsystem Factory Acceptance Tests.

- Completion of OTEC Pilot Plant System Quay-Side Test Readiness Review (TRR).

5.1.3 Phase 3 At Sea Activities

Completion of the OTEC Pilot Plant Quay-Side Integration & Test and Acceptance/Qualification activities and delivery of each to the site. This consists of the following:

- Completion of the Power Cycle (Remora) Element Horizontal Orientation Acceptance Tests.
- Completion of the Electrical Generation Turbine-Generator Segment Acceptance Tests.
- Completion of the Integrated Instrumentation and Control Segment Acceptance Tests.
- Completion of the Cold Water Pipe Fabrication System Installation & Check-out (INCO).
- Completion of the On-Shore Substation Subsystems Acceptance Tests.
- Completion of the Sea Keeping Element Installation.
- Completion of the CWP Fabrication and Deployment.
- Completion of the Power Delivery (Cabling) Installation and Acceptance Test.
- Completion of OTEC Pilot Plant System At Sea Test Readiness Review (TRR).

5.2 Test Conduct and Location

This SI&T will be conducted in three phases at three different sites; at the Shipyard, Quay-side in HI and "at sea" at the Pilot Plant site near Pearl Harbor Oahu, HI.

Phase 1 will be conducted at a Shipyard or similar facility where the OTEC Pilot Plant Platform will be constructed. The location for this activity is TBD.

Phase 2 will be conducted Quay-side in Hawaii. The location is TBD.

Phase 3 will be conducted "at Sea" on the selected site near Pearl Harbor Oahu, HI. Refer to Figure 5.2-1 for a map showing the location of the OTEC Pilot Plant.

All SI&T events will be performed at Pilot Plant site near Pearl Harbor Oahu, HI by the OTEC Pilot Plant Integration & Verification Team. All testing shall be conducted at the three Pilot Plant sites. All testing shall be performed in accordance with this Test Plan and Test Procedures and under the direction of an OTEC I&V Team Test Director. Deviations from this Test Plan require approval by the OTEC I&V Team Test Director and will be noted in the Test Procedures and further documented in the Test Report.

TBS

Figure 5.2-1 OTEC Pilot Plant Deployment Site Map

5.3 Participating Agencies and Responsibilities

5.3.1 Lockheed Martin– MS2 & SSC

LM-MS2, as the OTEC Team Lead, is responsible for the following:

- Coordination of the development of the Test Plan, Procedures and Report.
- Providing a Test Director and assembling test personnel for the test period.
- Coordination of the facilities/site preparations, Test Equipment, and support equipment for the test event.
- Providing Quality Assurance and Configuration Control of OTEC equipment and software.
- Coordination of data analysis and technical support.
- Coordination of status and quick-look reports.

5.3.2 Lockheed Martin OTEC Team (Partners)

The LM OTEC Team (Partners) are responsible for the following:

- Support of the development of the Test Plan, Procedures and Report.
- Support as test personnel and for technical evaluations for the test period.
- Support of the facilities/site preparations, Test Equipment, and support equipment for the test event.
- Support to Quality Assurance and Configuration Control of OTEC equipment and software.
- Support of data analysis and technical support.
- Support of status and quick-look reports.

5.3.3 USN NAVFAC (DoD)

NAVFAC, as the TBD, is responsible for the following:

- Reviewing and approving the Test Plan, Procedures and Report.
- Providing a Test Director and test witnessing for the test period.
- Other

5.3.4 US NOAA

NOAA, as the TBD, is responsible for the following:

- Reviewing and approving the Test Plan, Procedures and Report.
- Providing a Test Director and test witnessing for the test period.

- Other

5.3.5 US Department of Energy (DoE)

The DoE, as the TBD, is responsible for the following:

- Reviewing and approving the Test Plan, Procedures and Report.
- Providing a Test Director and test witnessing for the test period.
- Other

5.3.6 US Environmental Protection Agency (EPA)

The EPA, as the TBD, is responsible for the following:

- Reviewing and approving the Test Plan, Procedures and Report.
- Providing a Test Director and test witnessing for the test period.
- Other

5.4 Test Schedule

Table 5.4-1 - Test Schedule

Activity/Event	Relative to SI&T
Requirements Analysis	420 DPTT
Test Plan	360 DPTT
Test Plan *(Peer Review)* Inspection	330 DPTT
Test Plan Release	300 DPTT
Test Procedure (Preliminary)/*(Peer)* Inspections	220 DPTT
Dry Runs	90 DPTT
TRR Flip-Through/Trouble Report Critique	60 DPTT
Test Readiness Reviews	30 DPTT
Test Start	0
Quick Look Analysis	TBD
Debrief	TBD
Test Complete	TBD
Start Final Data Analysis	TBD
Complete Final Data Analysis	60 DATC
Test Procedures (Final) *("As Run")*	60 DATC
Test Report Review	83 DATC
Test Report Delivery	90 DATC

(DPTT = Day Prior To Test; DATC = Days After Test Completion)

Refer to Appendix B for the detailed test schedules.

6.0 ANALYSIS PLAN

This section contains the data requirements, planned analyses, evaluation criteria, and reporting requirements.

6.1 Data Collection

For each test conducted during the test period, the following data will be collected:

- Data recordings from TBD**.**
- Data recordings from the Integrated Instrumentation and Control Segment**.**
- Recorded events from the Event Data Acquisition System (DAS)**.**
- Recorded events from the Environment Data Acquisition System (EDAS)**.**
- Any other test unique measurement (i.e., waveform or strip chart recordings)**.**

The data will be assembled and entered into the test data recording system TBD, identifying the Test ID (run number), significant details of the test (from the Test Log), visual observations, and the test outcome.

6.2 Pass/Fail Criteria

The data will be assembled as each individual test is executed. The data collected will be analyzed to verify that test event requirements are satisfied.

Pass or Fail criteria are assessed against each test based on this analysis and comparison with the requirement paragraph cited for each event. This determination takes into account a comparison of the Expected Results with the Actual Results. The Pass/Fail criteria are explained below:

- Pass - A test event is considered to "Pass" when the objective(s) of the test is (are) met.
- Fail - A test event is considered to "Fail" when the test objective is not met. The corresponding SAR documents the failure identified with that event.

6.3 Required Reports

6.3.1 Daily Status Reports

Daily Status Reports will be issued and distributed, for each test, reporting test start, test progress and issues, and test completion. This will include anomalies observed during the test and found through data analysis, Trouble Reports generated, and troubleshooting steps.

6.3.2 Quick-Look Reports

A Quick-look Report will be produced and distributed, for each test, prior to the Test De-brief Meeting at the completion of the test. This will include confirmation of the Expected Results both observed during the test and found through data analysis after the test.

6.3.3 Test Report

A Final Test Report will be produced and delivered 90 days after test completion. The test report will include formal test results, data, and data analysis information. Final "As Run" Test Procedures will also be included (scanned, red-lined copy).

7.0 TEST CASE REQUIREMENTS AND DESCRIPTIONS

This section of the Test Plan outlines the test requirements for the OTEC Pilot Plant SI&T and is presented in contractor format. The individual test event descriptions are structured as follows:

Event Number and Title: This line identifies the name and number of the event.

Event Part Number and Title: This line identifies the name and number of the event part.

1) **Test Objective:** This section provides the objectives of the event. Test requirements from the TBD document, will provide the basis for each objective. Specific requirements are referenced for each event; therefore, they are not reiterated in each test description objective.
2) **Special Requirements**: This section provides information specific to each individual test, regarding test configurations, equipment needed, test execution requirements, instrumentation, or other pertinent details.
3) **Data to be Recorded**: This section identifies the type of data recording that will be necessary for this test event/part.
4) **Requirements Cross-Reference**: This section provides the paragraph number of the Requirements documents/specifications (e.g. SS, SSS, PIDS).
5) **Assumptions and Constraints**: This section details test assumptions and limitations relative to setup, conduct, configuration, expected results, and/or deviations, which may be required to execute the event.

PHASE 1 – Shipyard Installation and Test

7.1 Event 1 – Component and Subsystem Fabrication and Installation

These tests shall verify the proper installation of foundations and equipment for the Pilot Plant System delivered to the Shipyard/Builder's facility/site as described in section TBS of this plan.

7.1.1 Event 1 Part 1 - Platform Fabrication and Installation

These tests shall verify the proper installation of foundations and equipment for the Platform Segment as specified in TBS.

7.1.1.1 Event 1 Part 1A – Sea Keeping Fabrication and Installation

1) **Test Objective:**
   This test shall verify the proper installation of the Sea keeping Element attachment points on the Platform Topsides and Hull Elements as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The Platform Station keeping equipment will be installed during the At Sea test phase.

b. Tensioning attachment points and winch mountings will be installed for this test.
c. Electrical cabling that interfaces with the Sea keeping equipment will be installed for this test.

7.1.1.2 Event 1 Part 1B – Electrical Plant Fabrication and Installation

1) Test Objective:

This test shall verify the proper installation of foundations and equipment for the Platform Topsides Electrical Plant as specified in the TBD document.

2) Special Requirements:

TBS.

3) Requirements Cross Reference:

TBS.

4) Data to be Recorded:

a. Data recordings from the TBS.
b. Data from the TBS.

5) Assumptions and Constraints:

a. The Platform Topsides Electrical Plant equipment will consist of TBD.
b. TBD.

7.1.1.3 Event 1 Part 1C – Communications and Controls Fabrication and Installation

1) Test Objective:

This test shall verify the proper installation of foundations and equipment for the Platform Topsides Communication and Control Subsystem as specified in the TBD document.

2) Special Requirements:

TBS.

3) Requirements Cross Reference:

TBS.

4) Data to be Recorded:

a. Data recordings from the TBS.
b. Data from the TBS.

5) Assumptions and Constraints:

a. The Platform Topsides Communication and Control equipment will consist of TBD.
b. TBD.

7.1.1.4 Event 1 Part 1D – Auxiliary Systems Fabrication and Installation

1) Test Objective:

This test shall verify the proper installation of foundations and equipment for the Platform Topsides Auxiliary Systems Subsystem as specified in the TBD document.

2) Special Requirements:

TBS.

3) Requirements Cross Reference:

TBS.

4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The Platform Topsides Auxiliary Subsystems Subsystem equipment will consist of TBD.
   b. TBD.

7.1.1.5 Event 1 Part 1E – Outfit and Furnishings Fabrication and Installation

1) **Test Objective:**
   This test shall verify the proper installation of foundations and equipment for the Platform Topsides Outfit and Furnishing Subsystem as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The Platform Topsides Outfit and Furnishing Subsystem equipment will consist of TBD.
   b. TBD.

7.1.2 Event 1 Part 2 - Power Generation Fabrication and Installation

These tests shall verify the proper installation of foundations and equipment for the Power Generation Segment as specified in TBS.

7.1.2.1 Event 1 Part 2A – Power Cycle (Remora) Interfaces Fabrication and Installation

1) **Test Objective:**
   This test shall verify the proper installation of foundations for the Power Cycle (Remora) Subsystem as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Cross Reference to Requirements:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The Power Cycle (Remora) Subsystem equipment will be installed during the At Sea test phase.
   b. Remora attachment points on the Platform Topsides and Hull will be installed for this test.

c. Electrical cabling, ducting, and piping that interface with the Remora will be installed for this test (Ammonia piping, Pump electrical cabling, II&C signal cabling, and Crossover ducting).

7.1.2.2 Event 1 Part 2B – Cold Water Pipe Interfaces Fabrication and Installation

1) Test Objective:

This test shall verify the proper installation of foundations for the CWP Subsystem as specified in the TBD document.

2) Special Requirements:

TBS.

3) Cross Reference to Requirements:

TBS.

4) Data to be Recorded:

a. Data recordings from the TBS.

b. Data from the TBS.

5) Assumptions and Constraints:

a. The CWP Subsystem will be installed during the At Sea test phase.

b. CWP attachment points on the Platform Hull will be installed for this test.

c. Electrical cabling, ducting, and piping that interface with the CWP will be installed for this test (II&C signal cabling, and Crossover ducting).

7.1.2.3 Event 1 Part 2C – Electrical Generation (Turbine-Generator) Fabrication and Installation

1) Test Objective:

This test shall verify the proper installation of foundations for the Turbine-Generator Set as specified in the TBD document.

2) Special Requirements:

TBS.

3) Requirements Cross Reference:

TBS.

4) Data to be Recorded:

a. Data recordings from the TBS.

b. Data from the TBS.

5) Assumptions and Constraints:

a. The Electrical Generation equipment will consist of the Turbine-Generator Set, Generator Cooling, Turbine lubrication Oil, and Generator Field Exciter.

b. TBD.

7.1.3 Event 1 Part 3 Power Delivery Fabrication and Installation

These tests shall verify the proper installation of foundations and equipment for the Power Delivery Segment as specified in TBS.

7.1.3.1 Event 1 Part 3A – Platform Substation Fabrication and Installation

1) **Test Objective:**

   This test shall verify the proper installation of foundations for the Platform Substation components and equipment as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Platform Substation will consist of the Switchgear, Transformers, batteries, SCADA, power cabling and control cabling.

   b. TBD.

7.1.3.2 Event 1 Part 3B – Power Transmission (Cabling) Interfaces Fabrication and Installation

1) **Test Objective:**

   This test shall verify the proper installation of foundations for the Power Transmission Cabling components and equipment as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Power Transmission Cabling will consist of the Land cable, Undersea suspended cable, Undersea Seafloor cable, Undersea bottom-layed cable, and on-shore cable landing vault.

   b. TBD.

7.1.3.3 Event 1 Part 3C – On-shore Substation Fabrication and Installation (at selected site)

1) **Test Objective:**

   This test shall verify the proper installation of foundations for the On-shore Substation components and equipment as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The On-shore Substation will consist of the Switchgear, Transformers, batteries, SCADA, power cabling and control cabling.

b. TBD.

7.1.4 Event 1 Part 4 Integrated Instrumentation & Control (I&C) Fabrication and Installation

These tests shall verify the proper installation of foundations and equipment for the Integrated Instrumentation and Control Segment as specified in TBS.

7.1.4.1 Event 1 Part 4A – Platform I&C Fabrication and Installation

1) **Test Objective:**

This test shall verify the proper installation of foundations for the Platform Integrated Instrumentation & Control Subsystem as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The Platform Integrated Instrumentation & Control Subsystem will consist of TBS.

b. TBD.

7.1.4.2 Event 1 Part 4B – Power Cycle I&C Fabrication and Installation

1) **Test Objective:**

This test shall verify the proper installation of foundations for the Power Cycle Integrated Instrumentation & Control Subsystem as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The Power Cycle Integrated Instrumentation & Control Subsystem will consist of TBS.

b. TBD.

7.1.4.3 Event 1 Part 4C – Cold Water Pipe I&C Fabrication and Installation

1) **Test Objective:**

   This test shall verify the proper installation of foundations for the Cold Water Pipe Integrated Instrumentation & Control Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Cold Water Pipe Integrated Instrumentation & Control Subsystem will consist of TBS.

   b. TBD.

7.1.4.4 Event 1 Part 4D – Electrical Generation I&C Fabrication and Installation

1) **Test Objective:**

   This test shall verify the proper installation of foundations for the Electrical Generation Integrated Instrumentation & Control Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Electrical Generation Integrated Instrumentation & Control Subsystem will consist of TBS.

   b. TBD.

7.1.4.5 Event 1 Part 4E – Electrical Delivery I&C Fabrication and Installation

1) **Test Objective:**

   This test shall verify the proper installation of foundations for the Electrical Delivery Integrated Instrumentation & Control Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**
   a. The Electrical Delivery Integrated Instrumentation & Control Subsystem will consist of TBS.
   b. TBD.

7.1.4.6 Event 1 Part 4F – Environmental I&C Fabrication and Installation

1) **Test Objective:**
   This test shall verify the proper installation of foundations for the Environmental Integrated Instrumentation & Control Subsystem as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The Environmental Integrated Instrumentation & Control Subsystem will consist of TBS.
   b. TBD.

7.1.4.7 Event 1 Part 4G – Safety, Security, and Communications I&C Fabrication and Installation

1) **Test Objective:**
   This test shall verify the proper installation of foundations for the Safety, Security, and Communications Integrated Instrumentation & Control Subsystem as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The Safety, Security, and Communications Integrated Instrumentation & Control Subsystem will consist of TBS.
   b. TBD.

7.2 Event 2 – Components and Subsystems Light-Off

These tests shall verify the capability of the installed components and subsystems to be powered on properly and to interface correctly with supplied services (e.g. air, water, etc.).

7.2.1 Event 2 Part 1 Platform Light-Off

These tests shall verify the capability of the Platform components and subsystems to be powered on and to operate in a standalone state.

7.2.1.1 Event 2 Part 1A – Electrical Plant Light-Off

1) **Test Objective:**

   This test shall verify the proper power on and operation of the Platform Electrical Plant Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Platform Electrical Plant Subsystem will consist of TBS.

   b. TBD.

7.2.1.2 Event 2 Part 1B – Communications & Control Light-Off

1) **Test Objective:**

   This test shall verify the proper power on and operation of the Platform Communication and Control Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Platform Communication and Control Subsystem will consist of TBS.

   b. TBD.

7.2.1.3 Event 2 Part 1C – Auxiliary Systems Light-Off

1) **Test Objective:**

   This test shall verify the proper power on and operation of the Platform Auxiliary Subsystems as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The Platform Auxiliary Subsystems will consist of TBS.
   b. TBD.

7.2.1.4 Event 2 Part 1D – Outfit and Furnishings Light-Off

1) **Test Objective:**
   This test shall verify the proper power on and operation of the Platform Outfit & Furnishing Subsystems as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The Platform Outfit & Furnishing Subsystems will consist of TBS.
   b. TBD.

7.2.2 Event 2 Part 2 Power Generation Light-Off

These tests shall verify the capability of the Power Generation Segment components and subsystems to be powered on and to operate in a standalone state.

7.2.2.1 Event 2 Part 2A – Turbine Light-Off

1) **Test Objective:**
   This test shall verify the proper power on and operation of the Turbine Subsystem as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The Turbine Subsystem will consist of TBS.
   b. TBD.

7.2.2.2 Event 2 Part 2B – Generator Light-Off

1) **Test Objective:**

   This test shall verify the proper power on and operation of the Generator Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Generator Subsystem will consist of TBS.

   b. TBD.

7.2.3 Event 2 Part 3 Power Delivery Light-Off

These tests shall verify the capability of the Power Delivery Segment components and subsystems to be powered on and to operate in a standalone state.

7.2.3.1 Event 2 Part 3A – Platform Substation Light-Off

1) **Test Objective:**

   This test shall verify the proper power on and operation of the Platform Substation Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Platform Substation Subsystem will consist of TBS.

   b. TBD.

7.2.3.2 Event 2 Part 3B – On-Shore Substation Light-Off (at selected site)

1) **Test Objective:**

   This test shall verify the proper power on and operation of the On-Shore Substation Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The On-Shore Substation Subsystem will consist of TBS.
   b. TBD.

7.2.4 Event 2 Part 4 Integrated Instrumentation & Control Light-Off

These tests shall verify the capability of the Integrated Instrumentation & Control Segment components and subsystems to be powered on and to operate in a standalone state.

7.2.4.1 Event 2 Part 4A – Platform I&C Light-Off

1) **Test Objective:**
   This test shall verify the proper power on and operation of the Platform Instrumentation & Controls Subsystem as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The Platform Instrumentation & Controls Subsystem will consist of TBS.
   b. TBD.

7.2.4.2 Event 2 Part 4B – Power Cycle (Remoras) I&C Light-Off

1) **Test Objective:**
   This test shall verify the proper power on and operation of the Power Cycle Instrumentation & Controls Subsystem as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The Power Cycle Instrumentation & Controls Subsystem will consist of TBS.
   b. TBD.

7.2.4.3 Event 2 Part 4C – Cold Water Pipe I&C Light-Off

1) **Test Objective:**

   This test shall verify the proper power on and operation of the Cold Water Pipe Instrumentation & Controls Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Cold Water Pipe Instrumentation & Controls Subsystem will consist of TBS.

   b. TBD.

7.2.4.4 Event 2 Part 4D – Electrical Generation I&C Light-Off

1) **Test Objective:**

   This test shall verify the proper power on and operation of the Electrical Generation Instrumentation & Controls Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Electrical Generation Instrumentation & Controls Subsystem will consist of TBS.

   b. TBD.

7.2.4.5 Event 2 Part 4E – Electrical Delivery I&C Light-Off

1) **Test Objective:**

   This test shall verify the proper power on and operation of the Electrical Delivery Instrumentation & Controls Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Electrical Delivery Instrumentation & Controls Subsystem will consist of TBS.

b. TBD.

7.2.4.6 Event 2 Part 4F – Environmental I&C Light-Off

1) **Test Objective:**

This test shall verify the proper power on and operation of the Environmental Instrumentation & Controls Subsystem as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The Environmental Instrumentation & Controls Subsystem will consist of TBS.

b. TBD.

7.2.4.7 Event 2 Part 4G – Safety I&C Light-Off

1) **Test Objective:**

This test shall verify the proper power on and operation of the Safety Instrumentation & Controls Subsystem as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The Safety Instrumentation & Controls Subsystem will consist of TBS.

b. TBD.

7.2.4.8 Event 2 Part 4H – Security I&C Light-Off

1) **Test Objective:**

This test shall verify the proper power on and operation of the Security Instrumentation & Controls Subsystem as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**
   a. The Security Instrumentation & Controls Subsystem will consist of TBS.
   b. TBD.

7.2.4.9 Event 2 Part 4I – Communications I&C Light-Off

1) **Test Objective:**
   This test shall verify the proper power on and operation of the Communications Instrumentation & Controls Subsystem as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The Communications Instrumentation & Controls Subsystem will consist of TBS.
   b. TBD.

7.3 Event 3 – Element Integration and Test

These tests shall verify the capability of the OTEC Pilot Plant components and subsystems within the element to interface and operate properly.

7.3.1 Event 3 Part 1 Platform I&T

These tests shall verify the capability of the Platform element to operate properly. All Platform elements except for the Station keeping element subsystems will be involved in these tests.

7.3.1.1 Event 3 Part 1A – Electrical Plant I&T

1) **Test Objective:**
   This test shall verify the proper operation of the Platform Electrical Plant Subsystem as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The Platform Electrical Plant Subsystem will consist of TBS.
   b. TBD.

7.3.1.2 Event 3 Part 1B – Communication and Control I&T

1) **Test Objective:**

   This test shall verify the proper operation of the Platform Communication and Control Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Platform Communication and Control Subsystem will consist of TBS.

   b. TBD.

7.3.1.3 Event 3 Part 1C – Auxiliary Systems I&T

1) **Test Objective:**

   This test shall verify the proper operation of the Platform Auxiliary Systems Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Platform Auxiliary Systems Subsystem will consist of TBS.

   b. TBD.

7.3.1.4 Event 3 Part 1D – Outfit and Furnishings I&T

1) **Test Objective:**

   This test shall verify the proper operation of the Platform Outfit and Furnishing Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Platform Outfit and Furnishing Subsystem will consist of TBS.

b. TBD.

7.3.2 Event 3 Part 2 - Power Generation I&T

These tests shall verify the capability of the Power Generation element to operate properly. Only the Power Generation element Electrical Generation subsystem will be involved in these tests.

7.3.2.1 Event 3 Part 2A – Electrical Generation (Turbine-Generator) I&T

1) **Test Objective:**

   This test shall verify the proper operation of the Electrical Generation (Turbine-Generator Set) Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Electrical Generation (Turbine-Generator Set) Subsystem will consist of TBS.

   b. TBD.

7.3.3 Event 3 Part 3 - Power Delivery I&T

These tests shall verify the capability of the Power Delivery element to operate properly. All subsystems with the exception of the Transmission cabling will be involved in these tests.

7.3.3.1 Event 3 Part 3A – Platform Substation I&T

1) **Test Objective:**

   This test shall verify the proper operation of the Platform Substation Subsystem as specified in the TBD document.

1) **Special Requirements:**

   TBS.

2) **Requirements Cross Reference:**

   TBS.

3) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Platform Substation Subsystem will consist of TBS.

   b. TBD.

7.3.3.2 Event 3 Part 3B – On-Shore Substation I&T (at selected site)

1) **Test Objective:**

   This test shall verify the proper operation of the On-shore Substation Subsystem as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The On-shore Substation Subsystem will consist of TBS.

b. TBD.

7.3.4 Event 3 Part 4 - Integrated Instrumentation and Control I&T

These tests shall verify the capability of the Integrated Instrumentation and Control element to operate properly. Some of the components, subsystems or elements may be missing for these tests. Inputs from the missing components, subsystems or elements will be simulated or some type of other stimulation will be employed. Proper operation is tested for normal and various off-nominal and fault conditions.

7.3.4.1 Event 3 Part 4A – Platform Instrumentation & Control I&T

1) **Test Objective:**

This test shall verify the proper operation of the Platform I&C subsystem as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The Platform I&C subsystem will consist of TBS.

b. TBD.

7.3.4.2 Event 3 Part 4B – Power Cycle Instrumentation & Control I&T

1) **Test Objective:**

This test shall verify the proper operation of the Power Cycle I&C subsystem as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**
   a. The Power Cycle I&C subsystem will consist of TBS.
   b. TBD.

7.3.4.3 Event 3 Part 4C – Cold Water Pipe (CWP) Instrumentation & Control I&T

1) **Test Objective:**
   This test shall verify the proper operation of the CWP I&C subsystem as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The CWP I&C subsystem will consist of TBS.
   b. TBD.

7.3.4.4 Event 3 Part 4D – Power Cycle Instrumentation & Control I&T

1) **Test Objective:**
   This test shall verify the proper operation of the Power Cycle I&C subsystem as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The Power Cycle I&C subsystem will consist of TBS.
   b. TBD.

7.3.4.5 Event 3 Part 4E – Electrical Delivery Instrumentation & Control I&T

1) **Test Objective:**
   This test shall verify the proper operation of the Electrical Delivery I&C subsystem as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.

b. Data from the TBS.

5) Assumptions and Constraints:

a. The Electrical Delivery I&C subsystem will consist of TBS.

b. TBD.

7.3.4.6 Event 3 Part 4F – Environmental Instrumentation & Control I&T

1) Test Objective:

This test shall verify the proper operation of the Environmental I&C subsystem as specified in the TBD document.

2) Special Requirements:

TBS.

3) Requirements Cross Reference:

TBS.

4) Data to be Recorded:

a. Data recordings from the TBS.

b. Data from the TBS.

5) Assumptions and Constraints:

a. The Environmental I&C subsystem will consist of TBS.

b. TBD.

7.3.4.7 Event 3 Part 4G – Safety, Security, and Communication Instrumentation & Control I&T

1) Test Objective:

This test shall verify the proper operation of the Safety, Security, and Communication I&C subsystem as specified in the TBD document.

2) Special Requirements:

TBS.

3) Requirements Cross Reference:

TBS.

4) Data to be Recorded:

a. Data recordings from the TBS.

b. Data from the TBS.

5) Assumptions and Constraints:

a. The Safety, Security, and Communication I&C subsystem will consist of TBS.

b. TBD.

7.4 Event 4 – Integrated Instrumentation and Control I&C

These tests shall verify the capability of the Integrated Instrumentation and Control segment subsystems and elements within the segment to interface together and operate properly. Testing will include nominal and off-nominal conditions. Multiple anomalous conditions may be tested together.

7.4.1 Event 4 Part 1 - Platform Segment I&C Integration and Test

These tests shall verify the capability of the Platform Segment I&C to operate properly.

7.4.1.1 Event 4 Part 1A – TBD I&T

1) **Test Objective:**

   This test shall verify the proper operation of the TBD I&C subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The TBD I&C subsystem will consist of TBS.

   b. TBD.

7.4.1.2 Event 4 Part 1B – TBD I&T

1) **Test Objective:**

   This test shall verify the proper operation of the TBD I&C subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The TBD I&C subsystem will consist of TBS.

   b. TBD.

7.4.2 Event 4 Part 2 Power Generation Segment I&C I&T

These tests shall verify the capability of the Power Generation Segment I&C to operate properly.

7.4.2.1 Event 4 Part 2A – TBD I&T

1) **Test Objective:**

   This test shall verify the proper operation of the TBD I&C subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

b. Data from the TBS.

5) Assumptions and Constraints:

a. The TBD I&C subsystem will consist of TBS.

b. TBD.

7.4.2.2 Event 4 Part 2B – TBD I&T

1) Test Objective:

This test shall verify the proper operation of the TBD I&C subsystem as specified in the TBD document.

2) Special Requirements:

TBS.

3) Requirements Cross Reference:

TBS.

4) Data to be Recorded:

a. Data recordings from the TBS.

b. Data from the TBS.

5) Assumptions and Constraints:

a. The TBD I&C subsystem will consist of TBS.

b. TBD.

7.4.3 Event 4 Part 3 - Power Delivery Segment I&C Integration and Test

These tests shall verify the capability of the Power Delivery Segment I&C to operate properly.

7.4.3.1 Event 4 Part 3A – TBD I&T

1) Test Objective:

This test shall verify the proper operation of the TBD I&C subsystem as specified in the TBD document.

2) Special Requirements:

TBS.

3) Requirements Cross Reference:

TBS.

4) Data to be Recorded:

a. Data recordings from the TBS.

b. Data from the TBS.

5) Assumptions and Constraints:

a. The TBD I&C subsystem will consist of TBS.

b. TBD.

7.4.3.2 Event 4 Part 3B – TBD I&T

1) Test Objective:

This test shall verify the proper operation of the TDB I&C subsystem as specified in the TBD document.

2) Special Requirements:

TBS.

3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The TDB I&C subsystem will consist of TBS.
   b. TBD.

7.4.4 Event 4 Part 4 - Integrated Instrumentation and Control Segment I&T

These tests shall verify the capability of the Integrated Instrumentation and Control Segment to operate properly. All I&C elements will be included in these tests.

7.4.4.1 Event 4 Part 4A – TBD I&T

1) **Test Objective:**
   This test shall verify the proper operation of the TDB I&C subsystem as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The TDB I&C subsystem will consist of TBS.
   b. TBD.

7.4.4.2 Event 4 Part 4B – TBD I&T

1) **Test Objective:**
   This test shall verify the proper operation of the TDB I&C subsystem as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The TDB I&C subsystem will consist of TBS.
   b. TBD.

7.5 Event 5 – System Integration and Test (Limited)

These tests shall verify the capability of the OTEC Pilot Plant System segments, elements, and subsystems to interface together and operate properly. Since a number of components, subsystems and elements will/may be missing at this point the testing will be limited by the equipment available and installed. Missing equipment may be simulated or stimulated using special test equipment.

7.5.1 Event 5 Part 1 – System Start-Up

These tests shall verify the capability of the OTEC Pilot Plant System to power on and reach the start up state of operation.

7.5.1.1 Event 5 Part 1A – Initial System Conditions

1) **Test Objective:**
   This test shall verify the proper settings of equipment as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The equipment available for this test will consist of TBS.
   b. TBD.

7.5.1.2 Event 5 Part 1B – Initial Indications (Light-Off)

1) **Test Objective:**
   This test shall verify the proper indications and conditions once the equipment is powered on as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The equipment available for this test will consist of TBS.
   b. TBD.

7.5.1.3 Event 5 Part 1C – Steady State Conditions

1) **Test Objective:**
   This test shall verify the proper operation of equipment while in a steady state as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The equipment available for this test will consist of TBS.

b. TBD.

7.5.2 Event 5 Part 2 – Normal Operations

These tests shall verify the capability of the OTEC Pilot Plant System to operate under normal (no-fault, no-casualty) conditions.

7.5.2.1 Event 5 Part 2A – Full Capacity Operations

1) **Test Objective:**

This test shall verify the proper operation of equipment while in a normal full capacity state as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The equipment available for this test will consist of TBS.

b. TBD.

7.5.2.2 Event 5 Part 2B – Reduced (Partial) Capacity Operations

1) **Test Objective:**

This test shall verify the proper operation of equipment while in a normal reduced (partial) state as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The equipment available for this test will consist of TBS.

b. TBD.

7.5.2.3 Event 5 Part 2C – No Load Operations

1) **Test Objective:**

This test shall verify the proper operation of equipment while in a normal no load state as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The equipment available for this test will consist of TBS.

b. TBD.

7.5.3 Event 5 Part 3 – Casualty Operations

These tests shall verify the capability of the OTEC Pilot Plant System to operate, detect, and report faults or failures when experiencing equipment anomalies or failures.

7.5.3.1 Event 5 Part 3A – Cold Water Pump Fault/Off-line

1) **Test Objective:**

This test shall verify the proper operation of equipment while experiencing a Cold Water Pump fault as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The equipment available for this test will consist of TBS.

b. TBD.

7.5.3.2 Event 5 Part 3B – Warm Water Pump Fault/Off-line

1) **Test Objective:**

This test shall verify the proper operation of equipment while experiencing a Warm Water Pump fault as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.5.3.3 Event 5 Part 3C – Ammonia Pump Fault/Off-line

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing an Ammonia Pump fault as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The equipment available for this test will consist of TBS.
   b. TBD.

7.5.3.4 Event 5 Part 3D – Electrical System Fault/Off-line

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing an Electrical System TBD fault as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The equipment available for this test will consist of TBS.
   b. TBD.

7.5.3.5 Event 5 Part 3E – HVAC System Fault/Off-line

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing an HVAC System TBD fault as specified in the TBD document.
2) **Special Requirements:**
   TBS.

3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBD.

7.5.3.6 Event 5 Part 3F – Integrated Instrumentation & Control (II&C) System Fault/Off-line

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing an II&C System TBD fault as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBD.

7.5.3.7 Event 5 Part 3G – Turbine Fault/Off-line

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing a Turbine TBD fault as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBD.

7.5.3.8 Event 5 Part 3H – Generator Fault/Off-line

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing a Generator TBD fault as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBS.

b. TBD.

7.5.3.9 Event 5 Part 3I – Mooring/Station keeping System Fault/Off-line

1) **Test Objective:**

This test shall verify the proper operation of equipment while experiencing a Mooring System TBD fault as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBS.

b. TBD.

7.5.3.10 Event 5 Part 3J – Platform Substation Fault/Off-line

1) **Test Objective:**

This test shall verify the proper operation of equipment while experiencing an Platform Substation TBD fault as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBS.

b. TBD.

7.5.3.11 Event 5 Part 3K – On-shore Substation Fault/Off-line

1) **Test Objective:**

   This test shall verify the proper operation of equipment while experiencing an On-shore Substation TBD fault as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBS.

   b. TBD.

7.5.3.12 Event 5 Part 3L – TBD Fault/Off-line

1) **Test Objective:**

   This test shall verify the proper operation of equipment while experiencing a TBD fault as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   c. Data recordings from the TBS.

   d. Data from the TBS.

5) **Assumptions and Constraints:**

   c. TBS.

   d. TBD.

7.5.4 Event 5 Part 4 – Safety Hazards

These tests shall verify the capability of the OTEC Pilot Plant System to operate, detect, and report hazards when experiencing unsafe conditions.

7.5.4.1 Event 5 Part 4A – Fire Hazard/Condition

1) **Test Objective:**

   This test shall verify the proper operation of equipment while experiencing a Fire hazard as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.5.4.2 Event 5 Part 4B – Smoke Hazard/Condition

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing a Smoke hazard as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.5.4.3 Event 5 Part 4C – Flooding Hazard/Condition

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing a Flooding hazard as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.5.4.4 Event 5 Part 4D – Collision Hazard/Condition

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing a Collision hazard as specified in the TBD document.
2) **Special Requirements:**
   TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBS.

b. TBS.

7.5.4.5 Event 5 Part 4E – Abandon Ship Hazard/Condition

1) **Test Objective:**

This test shall verify the proper operation of equipment while experiencing an Abandon Ship hazard as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBS.

b. TBS.

7.5.4.6 Event 5 Part 4F – Ammonia Leak Hazard/Condition

1) **Test Objective:**

This test shall verify the proper operation of equipment while experiencing an Ammonia Leak hazard as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBS.

b. TBS.

7.5.4.7 Event 5 Part 4G – Storm Hazard/Condition

1) **Test Objective:**

This test shall verify the proper operation of equipment while experiencing a Storm hazard as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBS.

b. TBS.

7.5.4.8 Event 5 Part 4H – Intrusion Hazard/Condition

1) **Test Objective:**

This test shall verify the proper operation of equipment while experiencing an Intrusion hazard as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBS.

b. TBS.

7.5.4.9 Event 5 Part 4I – Flight Operations Hazard/Condition

1) **Test Objective:**

This test shall verify the proper operation of equipment while experiencing a Flight Operations hazard as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBS.

b. TBS.

7.5.4.10 Event 5 Part 4J – Resin/Catalyst Spill Hazard/Condition

1) **Test Objective:**

   This test shall verify the proper operation of equipment while experiencing a Resin/Catalyst Spill hazard as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBS.

   b. TBS.

7.5.5 Event 5 Part 5 – System Shut-Down

These tests shall verify the capability of the OTEC Pilot Plant System to operate properly while undergoing a Shutdown.

7.5.5.1 Event 5 Part 5A – Emergency Shut-Down

1) **Test Objective:**

   This test shall verify the proper operation of equipment while undergoing an Emergency Shut-Down as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBS.

   b. TBS.

7.5.5.2 Event 5 Part 5B – Normal Shut-Down

1) **Test Objective:**

   This test shall verify the proper operation of equipment while undergoing a Normal Shut-Down as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.5.5.3 Event 5 Part 5B – Cold Iron (All Power Removed) Shut-Down

1) **Test Objective:**
   This test shall verify the proper operation of equipment while undergoing a Cold Iron (All Power Removed) Shut-Down as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

PHASE 2 – Quay-Side Integration and Test

7.6 Event 6 – Component and Subsystem Installation

These tests shall verify the proper installation of foundations and equipment for the Pilot Plant System delivered to the Quay-side (dock) facility as described in section TBS of this plan.

7.6.1 Event 6 Part 1 - Cold Water Fabrication System

These tests shall verify the proper installation of foundations and equipment for the Cold Water Pipe Fabrication System as specified in TBS.

7.6.1.1 Event 6 Part 1A – Topside Equipment (Enclosure & Apparatus)

1) **Test Objective:**

   This test shall verify the proper installation of the CWP Fabrication System Fabrication Apparatus and Environmental Enclosure and interface/attachment points on the Platform Topsides Element as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The CWP Fabrication System equipment will be installed during the Quay-side test phase and operated in the At-Sea test phase.

   b. The CWP Fabrication System will consist of TBS.

   c. TBS.

7.6.1.2 Event 6 Part 1B – Hull Equipment (Gripper/Handler)

1) **Test Objective:**

   This test shall verify the proper installation of the CWP Fabrication System Gripper/Handler and interface/attachment points on the Platform Hull Element as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The CWP Fabrication System equipment will be installed during the Quay-side test phase and operated in the At-Sea test phase.

   b. TBS.

7.6.2 Event 6 Part 2 - TBD

These tests shall verify the capability of the *Pilot Plant System* to TBD.

7.6.2.1 Event 6 Part 2A – TBD

7.6.2.2 Event 6 Part 2B – TBD

7.7 Event 7 – Component and Subsystem Light-Off

These tests shall verify the capability of the installed components and subsystems to be powered on properly and to interface correctly with supplied services (e.g. air, water, etc.).

7.7.1 Event 7 Part 1 –Cold Water Pipe Environmental Enclosure Light-Off

These tests shall verify the capability of the CWP Fabrication Apparatus Environmental Enclosure components and subsystems to be powered on and to operate in a standalone state.

7.7.1.1 Event 7 Part 1A – Electrical Light-Off

1) **Test Objective:**

   This test shall verify the proper power on and operation of the CWP Fabrication Environmental Enclosure Electrical Plant Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The CWP FEE Electrical Subsystem will consist of TBS.

   b. TBD.

7.7.1.2 Event 7 Part 1B – HVAC Light-Off

1) **Test Objective:**

   This test shall verify the proper power on and operation of the CWP Fabrication Environmental Enclosure HVAC Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The CWP FEE HVAC Subsystem will consist of TBS.

   b. TBD.

7.7.1.3 Event 7 Part 1C – Material Handling (Core Planks, Shear Keys, Fabric Rolls, Resin) Light-Off

1) **Test Objective:**

   This test shall verify the proper power on and operation of the CWP Fabrication Environmental Enclosure Material Handling Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The CWP FEE Material Handling Subsystem will consist of TBS.

   b. TBD.

7.7.1.4 Event 7 Part 1D – Vacuum Supply Light-Off

1) **Test Objective:**

   This test shall verify the proper power on and operation of the CWP Fabrication Environmental Enclosure Vacuum Supply Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The CWP FEE Vacuum Supply Subsystem will consist of TBS.

   b. TBD.

7.7.1.5 Event 7 Part 1E – Compressed Air Supply Light-Off

1) **Test Objective:**

   This test shall verify the proper power on and operation of the CWP Fabrication Environmental Enclosure Compressed Air Supply Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**
   a. The CWP FEE Compressed Air Supply Subsystem will consist of TBS.
   b. TBD.

7.7.1.6 Event 7 Part 1F – Safety Systems Light-Off

1) **Test Objective:**
   This test shall verify the proper power on and operation of the CWP Fabrication Environmental Enclosure Safety Subsystem as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The CWP FEE Safety Subsystem will consist of TBS.
   b. TBD.

7.7.2 Event 7 Part 2 Cold Water Pipe Fabrication Apparatus

These tests shall verify the capability of the CWP Fabrication Apparatus components and subsystems to be powered on and to operate in a standalone state.

7.7.2.1 Event 7 Part 2A – Core Assembly Region Light-Off

1) **Test Objective:**
   This test shall verify the proper power on and operation of the CWP Fabrication Core Assembly Region Subsystem as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The CWP Fabrication Apparatus Core Assembly Region Subsystem will consist of TBS.
   b. TBD.

7.7.2.2 Event 7 Part 2B – Fabric Dispensing Region Light-Off

1) **Test Objective:**
   This test shall verify the proper power on and operation of the CWP Fabrication Fabric Dispensing Region Subsystem as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The CWP Fabrication Apparatus Fabric Dispensing Region Subsystem will consist of TBS.

b. TBD.

7.7.2.3 Event 7 Part 2C – Molding/VTRM Region Light-Off

1) **Test Objective:**

This test shall verify the proper power on and operation of the CWP Fabrication Molding/VTRM Region Subsystem as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The CWP Fabrication Apparatus Molding/VTRM Region Subsystem will consist of TBS.

b. TBD.

7.7.2.4 Event 7 Part 2D – Safety Systems Light-Off

1) **Test Objective:**

This test shall verify the proper power on and operation of the CWP Fabrication Safety Subsystem as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The CWP Fabrication Apparatus Safety Subsystem will consist of TBS.

b. TBD.

7.7.3 Event 7 Part 3 Cold Water Pipe Gripper/Handler Light-Off

These tests shall verify the capability of the CWP Fabrication Gripper/Handler components and subsystems to be powered on and to operate in a standalone state.

7.7.3.1 Event 7 Part 3A – Gripper Light-Off

1) **Test Objective:**

   This test shall verify the proper power on and operation of the CWP Fabrication Gripper Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The CWP Fabrication Gripper Region Subsystem will consist of TBS.

   b. TBD.

7.7.3.2 Event 7 Part 3B – Handler Light-Off

1) **Test Objective:**

   This test shall verify the proper power on and operation of the CWP Fabrication Handler Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The CWP Fabrication Handler Region Subsystem will consist of TBS.

   b. TBD.

7.7.3.3 Event 7 Part 3C – Safety Systems Light-Off

1) **Test Objective:**

   This test shall verify the proper power on and operation of the CWP Fabrication Griper/Handler Safety Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The CWP FEE Safety Region Subsystem will consist of TBS.
   b. TBD.

7.7.4 Event 7 Part 4 Integrated Instrumentation and Control Light-Off

These tests shall verify the capability of the II&C components and subsystems to be powered on and to operate in a standalone state.

7.7.4.1 Event 7 Part 4A – Cold Water Pipe Fabrication System Light-Off

1) **Test Objective:**
   This test shall verify the proper power on and operation of the CWP Fabrication System (Apparatus, Environmental Enclosure, and Gripper/Handler) as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The CWP Fabrication System will consist of the Fabrication Apparatus with Environmental Enclosure and the Gripper/Handler.
   b. TBD.

7.7.4.2 Event 7 Part 4B – TBD Light-Off

1) **Test Objective:**
   This test shall verify the proper power on and operation of the TBD System as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBD.
   b. TBD.

7.7.5 Event 7 Part 5 – Remora (Horizontal) Light-Off

These tests shall verify the capability of the Power Cycle (Remora) components and subsystems to be powered on and to operate in a standalone state. For these tests the Remora will be floating in a horizontal orientation. This configuration limits the amount of testing that is practical/ possible at this point.

7.7.5.1 Event 7 Part 5A – Connections to Turbine-Generator Light-Off

1) **Test Objective:**

   This test shall verify the proper power on and operation of the Remora Electrical Generation Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Remora Electrical Generation Subsystem will consist of TBD.

   b. TBD.

7.7.5.2 Event 7 Part 5B – Connections to Cold Water (CW) Source Light-Off

1) **Test Objective:**

   This test shall verify the proper power on and operation of the Remora CW Handling Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Remora CW Handling Subsystem will consist of TBD.

   b. TBD.

7.7.5.3 Event 7 Part 5C – Connections to Warm Water (WW) Source Light-Off

1) **Test Objective:**

   This test shall verify the proper power on and operation of the Remora WW Handling Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The Remora WW Handling Subsystem will consist of TBD.
   b. TBD.

7.7.5.4 Event 7 Part 5D – Connections to Electrical SupplySource Light-Off

1) **Test Objective:**
   This test shall verify the proper power on and operation of the Remora Electrical Supply Subsystem as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The Remora Electrical Supply Subsystem will consist of TBD.
   b. TBD.

7.7.5.5 Event 7 Part 5E – Connections to Ammonia Source Light-Off

1) **Test Objective:**
   This test shall verify the proper power on and operation of the Remora Ammonia Handling Subsystem as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The Remora Ammonia Handling Subsystem will consist of TBD.
   b. TBD.

7.8 Event 8 – Element/Segment Integration and Test

These tests shall verify the capability of the OTEC Pilot Plant components and subsystems within the element to interface and operate properly.

7.8.1 Event 8 Part 1 - Cold Water Pipe Fabrication System I&T

These tests shall verify the capability of the CWP Fabrication System to operate properly. All CWP Fabrication System segments will be involved in these tests.

7.8.1.1 Event 8 Part 1A – TBD

1) **Test Objective:**
   This test shall verify the proper power on and operation of the TBD as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The TBD will consist of TBD.
   b. TBD.

7.8.1.2 Event 8 Part 1B – TBD

1) **Test Objective:**
   This test shall verify the proper power on and operation of the TBD as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The TBD will consist of TBD.
   b. TBD.

7.8.2 Event 8 Part 2 - Integrated Instrumentation and Control I&T

These tests shall verify the capability of the II&C Segment elements to operate properly. All newly added II&C System elements will be involved in these tests.

7.8.2.1 Event 8 Part 2A – Cold Water Pipe Fabrication System Instrumentation and Control I&T

1) **Test Objective:**
   This test shall verify the proper interfacing and operation of the CWP Fabrication System I&C Subsystem as specified in the TBD document.
2) **Special Requirements:**
   TBS.

3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The CWP Fabrication System I&C Subsystem will consist of TBD.
   b. TBD.

7.8.2.2 Event 8 Part 2B – Environmental System Instrumentation and Control I&T

1) **Test Objective:**
   This test shall verify the proper interfacing and operation of the Environmental System Instrumentation & Control Subsystem as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The Environmental System I&C Subsystem will consist of TBD.
   b. TBD.

7.8.2.3 Event 8 Part 2C – Safety, Security, and Communication Instrumentation and Control I&T

1) **Test Objective:**
   This test shall verify the proper interfacing and operation of the Safety, Security and Communications System Instrumentation & Control Subsystem as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The Safety, Security and Communications I&C Subsystem will consist of TBD.
   b. TBD.

7.8.3 Event 8 Part 3 - Remora (Horizontal) I&T

These tests shall verify the capability of the Power Cycle (Remora) element components and subsystems to operate properly. All Remora subsystems will be involved in these tests.

7.8.3.1 Event 8 Part 3A – Turbine-Generator Element I&T

1) **Test Objective:**

   This test shall verify the proper interfacing and operation of the Remora Electrical Generation (Turbine Generator) Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Remora Electrical Generation Subsystem will consist of the Turbine-Generator Set, associated I&C, and TBD.

   b. TBD.

7.8.3.2 Event 8 Part 3B – Cold Water (CW) Subsystem/Path I&T

1) **Test Objective:**

   This test shall verify the proper interfacing and operation of the Remora CW Handling Subsystem as specified in the TBD document. The CWP will not be available for this test, so CW will be supplied by other means.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Remora CW Handling Subsystem will consist of the Condensors, pumps, associated I&C, piping, valves and ducting, corrosion & biofouling, and TBD.

   b. TBD.

7.8.3.3 Event 8 Part 3C – Warm Water (WW) Subsystem/Path I&T

1) **Test Objective:**

   This test shall verify the proper interfacing and operation of the Remora WW Handling Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

b. Data from the TBS.

5) Assumptions and Constraints:

a. The Remora WW Handling Subsystem will consist of the Evaporators, pumps, associated I&C, piping, valves and ducting, corrosion & biofouling, and TBD.

b. TBD.

7.8.3.4 Event 8 Part 3D – Ammonia Subsystem/Path I&T

1) Test Objective:

This test shall verify the proper interfacing and operation of the Remora WF (Ammonia) Handling Subsystem as specified in the TBD document.

2) Special Requirements:

TBS.

3) Requirements Cross Reference:

TBS.

4) Data to be Recorded:

a. Data recordings from the TBS.

b. Data from the TBS.

5) Assumptions and Constraints:

a. The Remora WF (Ammonia) Subsystem will consist of the pumps, Buffer/Storage Tanks, Demister, associated I&C, piping, valves and ducting, corrosion & biofouling, and TBD.

b. TBD.

7.8.3.5 Event 8 Part 3E – Electrical Supply Subsystem I&T

1) Test Objective:

This test shall verify the proper interfacing and operation of the Remora Electrical Supply Subsystem as specified in the TBD document.

2) Special Requirements:

TBS.

3) Requirements Cross Reference:

TBS.

4) Data to be Recorded:

a. Data recordings from the TBS.

b. Data from the TBS.

5) Assumptions and Constraints:

a. The Remora Electrical Supply Subsystem will consist of TBD.

b. TBD.

7.9 Event 9 – System Integration and Test (Partial)

These tests shall verify the capability of the OTEC Pilot Plant System segments, elements, and subsystems to interface together and operate properly. Since some components, subsystems and elements will/may be missing at this point the testing will be limited by the equipment available and installed. Missing equipment may be simulated or interfaces stimulated using special test equipment.

7.9.1 Event 9 Part 1 – Start-Up

These tests shall verify the capability of the OTEC Pilot Plant System to power on and reach the start up state of operation. The focus will be on the newly added equipment. Items missing/not present will be represented by Simulation/Stimulation test equipment as needed.

7.9.1.1 Event 9 Part 1A – Initial System Conditions

1) **Test Objective:**
   This test shall verify the proper settings of equipment as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The equipment available for this test will consist of TBS.
   b. TBD.

7.9.1.2 Event 9 Part 1B – Initial Indications (Light-Off)

1) **Test Objective:**
   This test shall verify the proper indications and conditions once the equipment is powered on as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The equipment available for this test will consist of TBS.
   b. TBD.

7.9.1.3 Event 9 Part 1C – Steady State Conditions

1) **Test Objective:**
   This test shall verify the proper operation of equipment while in a steady state as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.

4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The equipment available for this test will consist of TBS.
   b. TBD.

7.9.2 Event 9 Part 2 – Normal Operations

These tests shall verify the capability of the OTEC Pilot Plant System to operate under normal (no-fault, no-casualty) conditions. The focus will be on the newly added equipment. Items missing/not present will be represented by Simulation/Stimulation test equipment as needed.

7.9.2.1 Event 9 Part 2A – Full Capacity Operations

1) **Test Objective:**
   This test shall verify the proper operation of equipment while in a normal full capacity state as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The equipment available for this test will consist of TBS.
   c. TBD.

7.9.2.2 Event 9 Part 2B – Reduced (Partial) Capacity Operations

1) **Test Objective:**
   This test shall verify the proper operation of equipment while in a normal reduced (partial) capacity state as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The equipment available for this test will consist of TBS.
   b. TBD.

7.9.2.3 Event 9 Part 2C – No Load Operations

1) **Test Objective:**

   This test shall verify the proper operation of equipment while in a normal no load state as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The equipment available for this test will consist of TBS.

   b. TBD.

7.9.3 Event 9 Part 3 – Causality Operations

These tests shall verify the capability of the OTEC Pilot Plant System to operate, detect, and report faults or failures when experiencing equipment anomalies or failures. The focus will be on the newly added equipment. Items missing/not present will be represented by Simulation/Stimulation test equipment as needed.

7.9.3.1 Event 9 Part 3A – Cold Water Pump Fault/Off-line

1) **Test Objective:**

   This test shall verify the proper operation of equipment while experiencing a Cold Water Pump fault as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The equipment available for this test will consist of TBS.

   b. TBD.

7.9.3.2 Event 9 Part 3B – Warm Water Pump Fault/Off-line

1) **Test Objective:**

   This test shall verify the proper operation of equipment while experiencing a Warm Water Pump fault as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.9.3.3 Event 9 Part 3C – Ammonia Pump Fault/Off-line

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing an Ammonia Pump fault as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The equipment available for this test will consist of TBS.
   b. TBS.

7.9.3.4 Event 9 Part 3D – Electrical System Fault/Off-line

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing an Electrical System TBD fault as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The equipment available for this test will consist of TBS.
   b. TBS.

7.9.3.5 Event 9 Part 3E – HVAC System Fault/Off-line

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing an HVAC System TBD fault as specified in the TBD document.
2) **Special Requirements:**
   TBS.

3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The equipment available for this test will consist of TBS.
   b. TBS.

7.9.3.6 Event 9 Part 3F – Integrated Instrumentation & Control (II&C) System Fault/Off-line

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing an II&C System TBD fault as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The equipment available for this test will consist of TBS.
   b. TBS.

7.9.3.7 Event 9 Part 3G – Turbine Fault/Off-line

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing a Turbine TBD fault as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The equipment available for this test will consist of TBS.
   b. TBS.

7.9.3.8 Event 9 Part 3H – Generator Fault/Off-line

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing a Generator TBD fault as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The equipment available for this test will consist of TBS.

b. TBS.

7.9.3.9 Event 9 Part 3I – Mooring/Station keeping System Fault/Off-line

1) **Test Objective:**

This test shall verify the proper operation of equipment while experiencing a Mooring System TBD fault as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The equipment available for this test will consist of TBS.

b. TBS.

7.9.3.10 Event 9 Part 3J – Platform Substation Fault/Off-line

1) **Test Objective:**

This test shall verify the proper operation of equipment while experiencing a Platform Substation TBD fault as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The equipment available for this test will consist of TBS.

b. TBS.

7.9.3.11 Event 9 Part 3K – On-shore Substation Fault/Off-line

1) **Test Objective:**

   This test shall verify the proper operation of equipment while experiencing an On-shore Substation TBD fault as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The equipment available for this test will consist of TBS.

   b. TBS.

7.9.3.12 Event 9 Part 3L – TBD Fault/Off-line

1) **Test Objective:**

   This test shall verify the proper operation of equipment while experiencing a TBD fault as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The equipment available for this test will consist of TBS.

   b. TBS.

7.9.4 Event 9 Part 4 – Safety Hazards

These tests shall verify the capability of the OTEC Pilot Plant System to operate, detect, and report hazards when experiencing unsafe conditions. The focus will be on the newly added equipment. Items missing/not present will be represented by Simulation/Stimulation test equipment as needed.

7.9.4.1 Event 9 Part 4A – Fire Hazard/Condition

1) **Test Objective:**

   This test shall verify the proper operation of equipment while experiencing a Fire hazard as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.9.4.2 Event 9 Part 4B – Smoke Hazard/Condition

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing a Smoke hazard as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.9.4.3 Event 9 Part 4C – Flooding Hazard/Condition

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing a Flooding hazard as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.9.4.4 Event 9 Part 4D – Collision Hazard/Condition

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing a Collision hazard as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBS.

b. TBS.

7.9.4.5 Event 9 Part 4E – Abandon Ship Hazard/Condition

1) **Test Objective:**

This test shall verify the proper operation of equipment while experiencing an Abandon Ship hazard as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBS.

b. TBS.

7.9.4.6 Event 9 Part 4F – Ammonia Leak Hazard/Condition

1) **Test Objective:**

This test shall verify the proper operation of equipment while experiencing an Ammonia Leak hazard as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBS.

b. TBS.

7.9.4.7 Event 9 Part 4G – Storm Hazard/Condition

1) **Test Objective:**

   This test shall verify the proper operation of equipment while experiencing a Storm hazard as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBS.

   b. TBS.

7.9.4.8 Event 9 Part 4H – Intrusion Hazard/Condition

1) **Test Objective:**

   This test shall verify the proper operation of equipment while experiencing an Intrusion hazard as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBS.

   b. TBS.

7.9.4.9 Event 9 Part 4I – Flight Operations Hazard/Condition

1) **Test Objective:**

   This test shall verify the proper operation of equipment while experiencing a Flight Operations hazard as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBS.

b. TBS.

7.9.4.10 Event 9 Part 4J – Resin/Catalyst Spill Hazard/Condition

1) **Test Objective:**

This test shall verify the proper operation of equipment while experiencing a Resin/Catalyst Spill hazard as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBS.

b. TBS.

7.9.5 Event 9 Part 5 – System Shut-Down

These tests shall verify the capability of the OTEC Pilot Plant System to operate properly while undergoing a Shutdown. The focus will be on the newly added equipment. Items missing/not present will be represented by Simulation/Stimulation test equipment as needed.

7.9.5.1 Event 9 Part 5A – Emergency Shut-Down

1) **Test Objective:**

This test shall verify the proper operation of equipment while undergoing an Emergency Shut-Down as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBS.

b. TBS.

7.9.5.2 Event 9 Part 5B – Normal Shut-Down

1) **Test Objective:**

This test shall verify the proper operation of equipment while undergoing a Normal Shut-Down as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.9.5.3 Event 9 Part 5B – Cold Iron (All Power Removed) System Shut-Down

1) **Test Objective:**
   This test shall verify the proper operation of equipment while undergoing a Cold Iron (All Power Removed) Shut-Down as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

PHASE 3 – At Sea System Integration and Test

7.10 Event 10 – Component and Subsystem Installation

These tests shall verify the proper installation of foundations and equipment for the Pilot Plant System delivered to the At Sea (Deployment) site as described in section TBS of this plan.

7.10.1 Event 10 Part 1 - Platform Sea Keeping Element

These tests shall verify the proper installation of foundations and equipment for the Platform Station Keeping Element as specified in TBS.

7.10.1.1 Event 10 Part 1A – Tensioning

1) **Test Objective:**

   This test shall verify the proper installation of the Station Keeping Tensioning subsystem and interface/attachment points on the Platform as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Tensioning Subsystem will consist of TBS.

   b. TBS.

7.10.1.2 Event 10 Part 1B – Tensioning Members

1) **Test Objective:**

   This test shall verify the proper installation of the Station Keeping Tensioning Members subsystem and interface/attachment points on the Platform as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Tensioning Members Subsystem will consist of TBS.

   b. TBS.

7.10.1.3 Event 10 Part 1C – Seafloor Anchors

1) **Test Objective:**

This test shall verify the proper installation of the Station Keeping Seafloor Anchoring subsystem and interface/attachment points on the Platform as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The Seafloor Anchoring Subsystem will consist of TBS.

b. TBS.

7.10.2 Event 10 Part 2 - CWP Element Fabrication and Deployment

These tests shall verify the proper installation of foundations and equipment for the CWP Element Fabrication System as specified in TBS. The system will be operated and test specimens fabricated and verified prior to CWP Fabrication.

7.10.2.1 Event 10 Part 2A – Pipe and Instrumentation

1) **Test Objective:**

This test shall verify the proper fabrication of the CWP main structure and installed/imbedded instrumentation/sensors as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBS.

b. TBS.

7.10.2.2 Event 10 Part 2B – Termination

1) **Test Objective:**

This test shall verify the proper fabrication and attachment of the CWP Termination and installed/imbedded instrumentation/sensors as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) Assumptions and Constraints:

a. The CWP main structure will have completed fabrication prior to this test.

b. TBS.

c. TBS.

7.10.2.3 Event 10 Part 2C – Platform Attachment

1) Test Objective:

This test shall verify the proper fabrication and attachment of the CWP with Termination and installed/imbedded instrumentation/sensors to the Platform as specified in the TBD document.

2) Special Requirements:

TBS.

3) Requirements Cross Reference:

TBS.

4) Data to be Recorded:

a. Data recordings from the TBS.

b. Data from the TBS.

5) Assumptions and Constraints:

a. The CWP main structure and termination will have completed fabrication and attachment prior to this test.

b. TBS.

c. TBS.

7.10.2.4 Event 10 Part 2D – CW Ducting Installation (to Remora)

1) Test Objective:

This test shall verify the proper fabrication and attachment of the CW ducting from the CWP and installed/imbedded instrumentation/sensors to the Remora as specified in the TBD document.

2) Special Requirements:

TBS.

3) Requirements Cross Reference:

TBS.

4) Data to be Recorded:

a. Data recordings from the TBS.

b. Data from the TBS.

5) Assumptions and Constraints:

a. The completed CWP structure will have been attached to the Platform prior to this test.

b. TBS.

c. TBS.

7.10.2.5 Event 10 Part 2E – Integrated I&C Installation

1) Test Objective:

This test shall verify the proper operation of the completed CWP II&C as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The completed CWP and ducting to the Remora will have been installed prior to this test.

b. TBS.

c. TBS.

7.10.3 Event 10 Part 3 - Power Cycle (Remora) Element

These tests shall verify the proper installation of the Remora element along with Platform foundations and mounting/attachment points as specified in TBS. The Remora element will the Remora element be installed and made ready for testing in the vertical (deployed) orientation in a later test.

7.10.3.1 Event 10 Part 3A – Remora Upending and Attachment

1) **Test Objective:**

This test shall verify the proper handling and installation of the Remora element into the Platform Topsides and Hull structures as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The Remora will have been tested to the extent possible in the horizontal orientation prior to this test.

b. TBS.

7.10.3.2 Event 10 Part 3B – Remora Electrical System Installation/Connection

1) **Test Objective:**

This test shall verify the proper installation and testing of the Remora electrical supply subsystem as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The Remora electrical supply subsystem will have been tested to the extent possible in the horizontal orientation prior to this test.

b. TBS.

7.10.3.3 Event 10 Part 3C – Ammonia System Connection

1) **Test Objective:**

This test shall verify the proper installation and testing of the Remora ammonia supply subsystem as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The Remora ammonia supply subsystem will have been tested to the extent possible in the horizontal orientation prior to this test.

b. TBS.

7.10.3.4 Event 10 Part 3D –Remora Integrated I&C Connection

1) **Test Objective:**

This test shall verify the proper installation and testing of the Remora Integrated I&C subsystem as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The Remora Integrated I&C subsystem will have been tested to the extent possible in the horizontal orientation prior to this test.

b. TBS.

7.10.3.5 Event 10 Part 3E – CW System/Ducting Connection (from the CWP)

1) **Test Objective:**

This test shall verify the proper installation and testing of the Remora CW supply/ducting subsystem as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The Remora CW supply/ducting subsystem will have been tested to the extent possible in the horizontal orientation prior to this test.

b. TBS.

7.10.4 Event 10 Part 4 - Power Delivery Element

These tests shall verify the proper installation of the Power Delivery element subsystems/ components along with Platform foundations and mounting/attachment points as specified in TBS. This testing will focus on the newly installed equipment and interfaces.

7.10.4.1 Event 10 Part 4A – Subsea Power Cable Connections

1) **Test Objective:**

This test shall verify the proper installation of the Subsea Power Cable along with foundations and attachment points as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBS.

b. TBS.

7.10.4.2 Event 10 Part 4B – Subsea Power Cable Vault/Landing

1) **Test Objective:**

This test shall verify the proper installation of the Subsea Power Cable Vault/Landing equipment along with foundations and attachment points as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.10.4.3 Event 10 Part 4C – Land Cable Connections

1) **Test Objective:**
   This test shall verify the proper installation of the Land Power Cable along with foundations and attachment points as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.10.4.4 Event 10 Part 4D –Power cable I&C Connection

1) **Test Objective:**
   This test shall verify the proper installation of the Power Cable I&C along with foundations and attachment points as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.10.5 Event 10 Part 5 – Integrated I&C

These tests shall verify the proper installation of the II&C subsystems and elements along with foundations and mounting/attachment points as specified in TBS. This testing will focus on the newly installed equipment and interfaces, but will cover the entire segment.

7.10.5.1 Event 10 Part 5A – Platform I&C

1) **Test Objective:**

This test shall verify the proper installation of the Platform I&C along with foundations and attachment points as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBS.

b. TBS.

7.10.5.2 Event 10 Part 5B – Power Cycle I&C

1) **Test Objective:**

This test shall verify the proper installation of the Power Cycle I&C along with foundations and attachment points as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBS.

b. TBS.

7.10.5.3 Event 10 Part 5C – CWP I&C

1) **Test Objective:**

This test shall verify the proper installation of the CWP I&C along with foundations and attachment points as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBS.

b. TBS.

7.10.5.4 Event 10 Part 5D –Electrical Generation I&C

1) **Test Objective:**

   This test shall verify the proper installation of the Electrical Generation I&C along with foundations and attachment points as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBS.

   b. TBS.

7.10.5.5 Event 10 Part 5E – Electrical Delivery I&C

1) **Test Objective:**

   This test shall verify the proper installation of the Electrical Delivery I&C along with foundations and attachment points as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBS.

   b. TBS.

7.10.5.6 Event 10 Part 5F – Environmental I&C

1) **Test Objective:**

   This test shall verify the proper installation of the Environmental I&C along with foundations and attachment points as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBS.

b. TBS.

7.10.5.7 Event 10 Part 5G –Safety, Security & Communication I&C

1) **Test Objective:**

   This test shall verify the proper installation of the Safety, Security & Communication I&C along with foundations and attachment points as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBS.

   b. TBS.

7.11 Event 11 – Component and Subsystem Light-Off

These tests shall verify the capability of the installed components and subsystems to be powered on properly and to interface correctly with supplied services (e.g. air, water, etc.). These test will focus on the newly installed equipment but will cover all other equipment as well.

7.11.1 Event 11 Part 1 – Platform Light-Off

These tests shall verify the capability of the Platform components and subsystems to be powered on and to operate in a standalone state. These tests focus on newly added/installed equipment but cover all installed equipment.

7.11.1.1 Event 11 Part 1A –Electrical Plant Light-Off

1) **Test Objective:**

   This test shall verify the proper power on and operation of the Platform Electrical Plant Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Platform Electrical Plant Subsystem will consist of TBS.

   b. TBD.

7.11.1.2 Event 11 Part 1B –Communications Light-Off

1) **Test Objective:**

   This test shall verify the proper power on and operation of the Platform Communications Plant Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Platform Communications Subsystem will consist of TBS.

   b. TBD.

7.11.1.3 Event 11 Part 1C –Controls Light-Off

1) **Test Objective:**

   This test shall verify the proper power on and operation of the Platform Controls Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Platform Controls Subsystem will consist of TBS.

   b. TBD.

7.11.1.4 Event 11 Part 1D –Auxiliary Systems Light-Off

1) **Test Objective:**

   This test shall verify the proper power on and operation of the Platform Auxiliary Systems Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Platform Auxiliary Systems Subsystem will consist of TBS.

b. TBD.

7.11.1.5 Event 11 Part 1E –Outfit & Furnishing Light-Off

1) **Test Objective:**

This test shall verify the proper power on and operation of the Platform Outfit & Furnishing Subsystem as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The Platform Outfit & Furnishing Subsystem will consist of TBS.

b. TBD.

7.11.1.6 Event 11 Part 1F –Station keeping Light-Off

1) **Test Objective:**

This test shall verify the proper power on and operation of the Platform Station keeping Subsystem as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The Platform Station keeping Subsystem will consist of TBS.

b. TBD.

7.11.2 Event 11 Part 2 – Power Generation

These tests shall verify the capability of the Platform components and subsystems to be powered on and to operate in a standalone state. These tests focus on newly added/installed equipment but cover all installed equipment.

7.11.2.1 Event 11 Part 2A – Remora Electrical Subsystem

1) **Test Objective:**

This test shall verify the proper power on and operation of the Remora Electrical Supply Subsystem as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The Remora Electrical Supply Subsystem will consist of TBS.
   b. TBD.

7.11.2.2 Event 11 Part 2B – Remora Ammonia Subsystem

1) **Test Objective:**
   This test shall verify the proper power on and operation of the Remora Ammonia Supply Subsystem as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The Remora Ammonia Supply Subsystem will consist of TBS.
   b. TBD.

7.11.2.3 Event 11 Part 2C – Remora I&C Subsystem

1) **Test Objective:**
   This test shall verify the proper power on and operation of the Remora I&C Subsystem as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The Remora I&C Subsystem will consist of TBS.
   b. TBD.

7.11.3 Event 11 Part 3 – Power Delivery

These tests shall verify the capability of the Power Delivery components and subsystems to be powered on and to operate in a standalone state. These tests focus on newly added/installed equipment but cover all installed equipment.

7.11.3.1 Event 11 Part 3A – Subsea Power Transmission Cabling/Connection Tests

1) **Test Objective:**

   This test shall verify the proper power on and operation of the Subsea Power Transmission Cabling Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Subsea Power Transmission Cabling Subsystem will consist of TBS.

   b. TBD.

7.11.3.2 Event 11 Part 3B – Land Power Transmission Cabling/Connection Tests

1) **Test Objective:**

   This test shall verify the proper power on and operation of the Land Power Transmission Cabling Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Land Power Transmission Cabling Subsystem will consist of TBS.

   b. TBD.

7.11.3.3 Event 11 Part 3C – Platform Substation Tests

1) **Test Objective:**

   This test shall verify the proper power on and operation of the Platform Substation Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Subsea Power Transmission Cabling Subsystem will consist of TBS.

b. TBD.

7.11.3.4 Event 11 Part 3D – On-Shore Substation Tests

1) **Test Objective:**

   This test shall verify the proper power on and operation of the On-Shore Substation Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The On-Shore Substation Subsystem will consist of TBS.

   b. TBD.

7.11.4 Event 11 Part 4 – Integrated I&C

These tests shall verify the capability of the II&C components and subsystems to be powered on and to operate in a standalone state. These tests focus on newly added/installed equipment but cover all installed equipment..

7.11.4.1 Event 11 Part 4A – Platform I&C

1) **Test Objective:**

   This test shall verify the proper power on and operation of the Platform II&C Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. The Platform II&C Subsystem will consist of TBS.

   b. TBD.

7.11.4.2 Event 11 Part 4B – Power Cycle I&C

1) **Test Objective:**

   This test shall verify the proper power on and operation of the Power Cycle II&C Subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The Power Cycle II&C Subsystem will consist of TBS.
   b. TBD.

7.11.4.3 Event 11 Part 4C – CWP I&C

1) **Test Objective:**
   This test shall verify the proper power on and operation of the CWP II&C Subsystem as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The CWP II&C Subsystem will consist of TBS.
   b. TBD.

7.11.4.4 Event 11 Part 4D –Electrical Generation I&C

1) **Test Objective:**
   This test shall verify the proper power on and operation of the Electrical Generation II&C Subsystem as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. The Electrical Generation II&C Subsystem will consist of TBS.
   b. TBD.

7.11.4.5 Event 11 Part 4E – Electrical Delivery I&C

1) **Test Objective:**
   This test shall verify the proper power on and operation of the Electrical Delivery II&C Subsystem as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The Electrical Delivery II&C Subsystem will consist of TBS.

b. TBD.

7.11.4.6 Event 11 Part 4F – Environmental I&C

1) **Test Objective:**

This test shall verify the proper power on and operation of the Environmental II&C Subsystem as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The Environmental II&C Subsystem will consist of TBS.

b. TBD.

7.11.4.7 Event 11 Part 4G –Safety, Security & Communication I&C

1) **Test Objective:**

This test shall verify the proper power on and operation of the Safety, Security & Communication II&C Subsystem as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. The Safety, Security & Communication II&C Subsystem will consist of TBS.

b. TBD.

7.12 Event 12 – Element Integration and Test

These tests shall verify the capability of the OTEC Pilot Plant components and subsystems within the element to interface and operate properly.

7.12.1 Event 12 Part 1 – Platform

These tests shall verify the capability of Platform elements & subsystems to operate properly. All Platform elements and subsystems will be involved in these tests. The focus will be on newly installed equipment but will also cover all equipment.

7.12.1.1 Event 12 Part 1A –Electrical Plant Subsystem I&T

1) **Test Objective:**

   This test shall verify the interoperability of the Platform Electrical Plant subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBD.

   b. TBD.

7.12.1.2 Event 12 Part 1B –Communications Subsystem I&T

1) **Test Objective:**

   This test shall verify the interoperability of the Platform Communications subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBD.

   b. TBD.

7.12.1.3 Event 12 Part 1C –Controls Subsystem I&T

1) **Test Objective:**

   This test shall verify the interoperability of the Platform Controls subsystem as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBD.

b. TBD.

7.12.1.4 Event 12 Part 1D –Auxiliary Systems Subsystem I&T

1) **Test Objective:**

This test shall verify the proper interoperability of the Platform Auxiliary Systems subsystem as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBD.

b. TBD.

7.12.1.5 Event 12 Part 1E –Outfit & Furnishing Subsystem I&T

1) **Test Objective:**

This test shall verify the proper interoperability of the Platform Outfit & Furnishing subsystem as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBD.

b. TBD.

7.12.1.6 Event 12 Part 1F –Station keeping Subsystem I&T

1) **Test Objective:**

   This test shall verify the proper interoperability of the Platform Station keeping subsystem as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBD.

   b. TBD.

7.12.2 Event 12 Part 2 – Power Generation

These tests shall verify the capability of Power Generation Segment elements & subsystems to operate properly. All Power Generation elements will be involved in these tests. The focus will be on newly installed equipment but will involve all equipment.

7.12.2.1 Event 12 Part 2A – Remora to Turbine-Generator Set

1) **Test Objective:**

   This test shall verify the proper interoperability of the Power Cycle (Remora) and the Electrical Generation (Turbine Generator Set) elements as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBD.

   b. TBD.

7.12.2.2 Event 12 Part 2B – Remora to CWP

1) **Test Objective:**

   This test shall verify the proper interoperability of the Power Cycle (Remora) and the Cold Water Pipe elements as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBD.
   b. TBD.

7.12.3 Event 12 Part 3 – Power Delivery

These tests shall verify the capability of the Power Delivery Segment elements & subsystems to operate properly. All Power Delivery elements will be involved in these tests. The focus will be on newly installed equipment but will involve all equipment.

7.12.3.1 Event 12 Part 3A – Subsea Power Cabling to Land Power cabling

1) **Test Objective:**
   This test shall verify the proper interoperability of the Subsea and Land Power cabling components as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBD.
   b. TBD.

7.12.3.2 Event 12 Part 3B – Platform Substation to Power Cabling Connection Tests

1) **Test Objective:**
   This test shall verify the proper interoperability of the Platform Substation and Power cabling subsystems as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBD.
   b. TBD.

7.12.3.3 Event 12 Part 3C – On-Shore Substation to Power Cabling Connection Tests

1) **Test Objective:**

   This test shall verify the proper interoperability of the On-shore Substation and Power cabling subsystems as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBD.

   b. TBD.

7.12.4 Event 12 Part 4 – Integrated I&C

These tests shall verify the capability of II&C Segment elements & subsystems to operate properly. All Power Delivery elements will be involved in these tests. The focus will be on newly installed equipment but will involve all equipment.

7.12.4.1 Event 12 Part 4A – Platform Management - Safety, Security & Communication

1) **Test Objective:**

   This test shall verify the proper interoperability of the Platform Management Safety, Security, and Communications I&C subsystems as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBD.

   b. TBD.

7.12.4.2 Event 12 Part 4B – Platform Management (new items)

1) **Test Objective:**

   This test shall verify the proper interoperability of the Platform Management TBD I&C subsystems as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBD.
   b. TBD.

7.12.4.3 Event 12 Part 4C – Power Management - Power Cycle

1) **Test Objective:**
   This test shall verify the proper interoperability of the Power Management Power Cycle I&C subsystems as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBD.
   b. TBD.

7.12.4.4 Event 12 Part 4D – Power Management - CWP

1) **Test Objective:**
   This test shall verify the proper interoperability of the Power Management Cold Water Pipe I&C subsystems as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBD.
   b. TBD.

7.12.4.5 Event 12 Part 4E – Power Management - Electrical Generation

1) **Test Objective:**
   This test shall verify the proper interoperability of the Power Management Electrical Generation I&C subsystems as specified in the TBD document.
2) **Special Requirements:**
   TBS.

3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBD.
   b. TBD.

7.12.4.6 Event 12 Part 4F – Power Management - Electrical Delivery

1) **Test Objective:**
   This test shall verify the proper interoperability of the Power Management Electrical Delivery I&C subsystems as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBD.
   b. TBD.

7.12.4.7 Event 12 Part 4G – Environmental Management (new items)

1) **Test Objective:**
   This test shall verify the proper interoperability of the Environmental Management I&C subsystems as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBD.
   b. TBD.

7.13 Event 13 – Segment Integration and Test

These tests shall verify the capability of the OTEC Pilot Plant components, subsystems, elements within the segment to interface and operate properly.

7.13.1 Event 13 Part 1 – Platform to Power Generation

These tests shall verify the capability of the Platform Segment components to interface and operate properly with the Power Generation Segment components. All segment elements will be involved in these tests.

1) **Test Objective:**

   This test shall verify the proper power on and operation of the Platform to Power Generation Segment as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBD.

   b. TBD.

7.13.2 Event 13 Part 2 – Platform to Power Delivery

These tests shall verify the capability of the Platform Segment components to interface and operate properly with the Power Delivery Segment components. All segment elements will be involved in these tests.

1) **Test Objective:**

   This test shall verify the proper power on and operation of the Platform to Power Delivery Segment as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBD.

   b. TBD.

7.13.3 Event 13 Part 3 – Platform to II&C

These tests shall verify the capability of the Platform Segment components to interface and operate properly with the II&C Segment components. All segment elements will be involved in these tests.

1) **Test Objective:**

   This test shall verify the proper power on and operation of the Platform to II&C Segment as specified in the TBD document.

2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBD.
   b. TBD.

7.13.4 Event 13 Part 4 – Platform to CWP Fabrication System

These tests shall verify the capability of the Platform Segment components to interface and operate properly with the CWP Fabrication System components. All segment elements will be involved in these tests.

1) **Test Objective:**
   This test shall verify the proper power on and operation of the Platform Segment interfaces to the CWP Fabrication System as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBD.
   b. TBD.

7.13.5 Event 13 Part 5 – Power Generation to Power Delivery

These tests shall verify the capability of the Power Generation Segment components to interface and operate properly with the Power Delivery Segment components. All segment elements will be involved in these tests.

1) **Test Objective:**
   This test shall verify the proper power on and operation of the Power Generation to Power Delivery Segments as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.

5) **Assumptions and Constraints:**
   a. TBD.
   b. TBD.

7.13.6 Event 13 Part 6 – Power Generation to II&C

These tests shall verify the capability of the Power Generation Segment components to interface and operate properly with the II&C Segment components. All segment elements will be involved in these tests.

1) **Test Objective:**
   This test shall verify the proper power on and operation of the Power Generation to II&C Segments as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBD.
   b. TBD.

7.13.7 Event 13 Part 7 – Power Delivery to II&C

These tests shall verify the capability of the Power Delivery Segment components to interface and operate properly with the II&C Segment components. All segment elements will be involved in these tests.

1) **Test Objective:**
   This test shall verify the proper power on and operation of the Power Delivery to II&C Segment as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBD.
   b. TBD.

7.13.8 Event 13 Part 8 – II&C to all components, subsystems and elements

These tests shall verify the capability of the II&C Segment components to interface and operate properly with all other Segment components.

1) **Test Objective:**
   This test shall verify the proper power on and operation of the II&C with o all other Segment subsystems and elements as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBD.
   b. TBD.

7.14 Event 14 – System Integration and Test

These tests shall verify the capability of the OTEC Pilot Plant System segments, elements, and subsystems to interface together and operate properly. All Segments and their components will be involved in these tests.

7.14.1 Event 14 Part 1 – Start-Up

These tests shall verify the capability of the OTEC Pilot Plant System to power on and reach the start up state of operation..

7.14.1.1 Event 14 Part 1A – Initial System Conditions

1) **Test Objective:**
   This test shall verify the proper settings of all equipment as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBD.
   b. TBD.

7.14.1.2 Event 14 Part 1B – Initial Indications (Light-Off)

1) **Test Objective:**
   This test shall verify the proper indications and conditions once all equipment is powered on as specified in the TBD document.
2) **Special Requirements:**
   TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBD.

b. TBD.

7.14.1.3 Event 14 Part 1C – Steady State Conditions

1) **Test Objective:**

This test shall verify the proper operation of all equipment while in a steady state as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBD.

b. TBD.

7.14.2 Event 14 Part 2 – Normal Operations

These tests shall verify the capability of the OTEC Pilot Plant System to operate under normal (no-fault, no-casualty) conditions.

7.14.2.1 Event 14 Part 2A – Full Capacity Operations

1) **Test Objective:**

This test shall verify the proper operation of all equipment while in a normal full capacity state as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBD.

b. TBD.

7.14.2.2 Event 14 Part 2B – Reduced Capacity Operations

1) **Test Objective:**

   This test shall verify the proper operation of all equipment while in a normal reduced (partial) capacity state as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBD.

   b. TBD.

7.14.2.3 Event 14 Part 2CB – No Load Operations

1) **Test Objective:**

   This test shall verify the proper operation of all equipment while in a normal no load state as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBD.

   b. TBD.

7.14.3 Event 14 Part 3 – Causality Operations

These tests shall verify the capability of the OTEC Pilot Plant System to operate, detect, and report faults or failures when experiencing equipment anomalies or failures.

7.14.3.1 Event 14 Part 3A – Cold Water Pump Fault/Off-line

1) **Test Objective:**

   This test shall verify the proper operation of equipment while experiencing a Cold Water Pump fault as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBD.
   b. TBD.

7.14.3.2 Event 14 Part 3B – Warm Water Pump Fault/Off-line

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing a Warm Water Pump fault as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.14.3.3 Event 14 Part 3C – Working Fluid (Ammonia) Pump Fault/Off-line

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing a Working Fluid (Ammonia) Pump fault as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.14.3.4 Event 14 Part 3D – Electrical System Fault/Off-line

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing an Electrical System fault as specified in the TBD document.
2) **Special Requirements:**
   TBS.

3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.14.3.5 Event 14 Part 3E – HVAC System Fault/Off-line

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing a HVAC System fault as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.14.3.6 Event 14 Part 3F – II&C System Fault/Off-line

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing an II&C System II&C System fault as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.14.3.7 Event 14 Part 3G – Turbine Fault/Off-line

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing a Turbine fault as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBS.

b. TBS.

7.14.3.8 Event 14 Part 3H – Generator Fault/Off-line

1) **Test Objective:**

This test shall verify the proper operation of equipment while experiencing a Generator fault as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBS.

b. TBS.

7.14.3.9 Event 14 Part 3I – Mooring/Station keeping Fault/Off-line

1) **Test Objective:**

This test shall verify the proper operation of equipment while experiencing a Mooring/Station keeping fault as specified in the TBD document.

2) **Special Requirements:**

TBS.

3) **Requirements Cross Reference:**

TBS.

4) **Data to be Recorded:**

a. Data recordings from the TBS.

b. Data from the TBS.

5) **Assumptions and Constraints:**

a. TBS.

b. TBS.

7.14.3.10 Event 14 Part 3J – Platform Stabilization Fault/Off-line

1) **Test Objective:**

   This test shall verify the proper operation of equipment while experiencing a Platform Stabilization fault as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBS.

   b. TBS.

7.14.3.11 Event 14 Part 3K – TBD Fault/Off-line

1) **Test Objective:**

   This test shall verify the proper operation of equipment while experiencing a TBD fault as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBS.

   b. TBS.

7.14.3.12 Event 14 Part 3L – TBD Fault/Off-line

1) **Test Objective:**

   This test shall verify the proper operation of equipment while experiencing a TBD fault as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBS.

b. TBS.

7.14.4 Event 14 Part 4 – Safety Hazards

These tests shall verify the capability of the OTEC Pilot Plant System to operate, detect, and report hazards when experiencing unsafe conditions.

7.14.4.1 Event 14 Part 4A – Fire

1) **Test Objective:**

   This test shall verify the proper operation of equipment while experiencing a Fire hazard as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBS.

   b. TBS.

7.14.4.2 Event 14 Part 4B – Smoke

1) **Test Objective:**

   This test shall verify the proper operation of equipment while experiencing a Smoke hazard as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBS.

   b. TBS.

7.14.4.3 Event 14 Part 4C – Flooding

1) **Test Objective:**

   This test shall verify the proper operation of equipment while experiencing a Flooding hazard as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.14.4.4 Event 14 Part 4D – Collision

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing a Collision hazard as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.14.4.5 Event 14 Part 4E – Abandon Ship

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing an Abandon Ship hazard as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.14.4.6 Event 14 Part 4F – Ammonia Leak

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing an Ammonia Leak hazard as specified in the TBD document.
2) **Special Requirements:**
   TBS.

3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.14.4.7 Event 14 Part 4G – Storm

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing a Storm hazard as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.14.4.8 Event 14 Part 4H – Intrusion

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing a Intrusion hazard as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.14.4.9 Event 14 Part 4I – Flight Operations

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing a Flight Operations hazard as specified in the TBD document.

2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.14.4.10 Event 14 Part 4J – Resin or Catalyst Spill

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing a Resin or Catalyst Spill hazard as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.14.4.11 Event 14 Part 4K – TBS

1) **Test Objective:**
   This test shall verify the proper operation of equipment while experiencing a TBS hazard as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.14.5 Event 14 Part 5 – System Shut-Down

These tests shall verify the capability of the OTEC Pilot Plant System to operate properly while undergoing a Shutdown.

7.14.5.1 Event 14 Part 5A – Emergency Shut-Down

1) **Test Objective:**

   This test shall verify the proper operation of equipment while undergoing an Emergency Shut-Down as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBS.

   b. TBS.

7.14.5.2 Event 14 Part 5B – Normal Shut-Down

1) **Test Objective:**

   This test shall verify the proper operation of equipment while undergoing a Normal Shut-Down as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBS.

   b. TBS.

7.14.5.3 Event 14 Part 5C – Power-Down (Cold Iron)

1) **Test Objective:**

   This test shall verify the proper operation of equipment while undergoing an Power-Down as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.15 Event 15 – CWP Fabrication System Removal

These tests shall verify the capability of the Pilot Plant System to operate after removal of the CWP Fabrication System equipment.

7.15.1 Event 15 Part 1 – Environmental Enclosure Segment

These tests shall verify the operational integrity of the Pilot Plant System after removal of the Environmental Enclosure Segment.

1) **Test Objective:**
   This test shall verify the proper operation of equipment once the Environmental Enclosure is removed as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.
   b. TBS.

7.15.2 Event 15 Part 2 – Gripper/Handler Segment

These tests shall verify the operational integrity of the Pilot Plant System after removal of the Gripper Handler Segment.

1) **Test Objective:**
   This test shall verify the proper operation of equipment once the Gripper/Handler equipment has been removed as specified in the TBD document.
2) **Special Requirements:**
   TBS.
3) **Requirements Cross Reference:**
   TBS.
4) **Data to be Recorded:**
   a. Data recordings from the TBS.
   b. Data from the TBS.
5) **Assumptions and Constraints:**
   a. TBS.

b. TBS.

7.15.3 Event 15 Part 3 – Fabrication Apparatus

These tests shall verify the operational integrity of the Pilot Plant System after removal of the Fabrication Apparatus Segment.

1) **Test Objective:**

   This test shall verify the proper operation of equipment once the Fabrication Apparatus has been removed as specified in the TBD document.

2) **Special Requirements:**

   TBS.

3) **Requirements Cross Reference:**

   TBS.

4) **Data to be Recorded:**

   a. Data recordings from the TBS.

   b. Data from the TBS.

5) **Assumptions and Constraints:**

   a. TBS.

   b. TBS.

APPENDIX A – Abbreviations & Acronyms

BIT	Built In Test
BITE	Built In Test Equipment
CW	Cold Water
CWP	Cold Water Pipe
DAS	Data Acquisition System
DATC	Days After Completion of Test
DPPT	Days Prior to Test
EDAS	Environmental Data Acquisition System
LM	Lockheed Martin Corporation
OTEC	Ocean Thermal Energy Conversion
RVTM	Requirements Verification Traceability Matrix
SI	System Integration
SI&T	System Integration and Test
WF	Working Fluid
WW	Warm Water

APPENDIX B – Test Schedule & Milestones

APPENDIX C – Requirements Verification/Traceability Matrix (RVTM)

APPENDIX D – Test Configurations

Phase 1

Phase 2

Phase 3

APPENDIX E – Trouble/System Anomaly Reports

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 4.1-3
OTEC Pilot Plant to Grid Interface Test Plan Draft
OTEC-2010-001

17 September 2010

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for the

OTEC Pilot Plant

to the

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APPROVAL PAGE

Draft
Test Plan
for the
OTEC Pilot Plant to Grid Interface

Revision: Draft

12 July 2010

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REVISION RECORD

Revision	Date	Description of & Reason for Changes
Draft	12 July 2010	Initial Draft for Review

ABSTRACT/FOREWORD

This Test Plan describes the test requirements, objectives, events, and configurations necessary for conducting the OTEC Pilot Plant to Local Electrical Power Grid Interface Test event. This test will integrate the OTEC Pilot Plant System On-Shore Substation to/with the local Onshore Electrical Power Grid.

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1 INTRODUCTION

This OTEC Pilot Plant to Grid Interface Test Plan documents the test requirements, objectives, events, and test configurations for conducting the OTEC Pilot Plant Grid Interface Test event. This Test will integrate the OTEC Pilot Plant System (and OTEC On-Shore Substation) with the local Onshore Electrical Power Grid. A list of abbreviation and acronyms used is provided in Appendix A. The schedule of test activities is provided as Appendix B.

1.1 Purpose of the Test

The purpose of this Test is to integrate and functionally test the OTEC Pilot Plant System interface to the local On-shore Electrical Power Grid. For the purposes of this Test Plan the OTEC Pilot Plant System is defined as the following:

- OTEC Pilot Plant System:
  - Platform, Power Generation, and Integrated Instrumentation & Control Segments
  - Power Delivery Segment
    - Platform Substation
    - Power Transmission Cabling (form the Pilot Plant to Shore)
    - On-shore Substation
- Local On-shore Electrical Power Grid System:
  - TBS
  - TBS

1.2 Test Objectives

The Overall objectives of this Test are to verify that the OTEC Pilot Plant to Grid Interface meets the requirements specified in the TBD Interface Specification and the TBD Acceptance Test Requirements document. The Requirements to Test traceability matrix is located in Appendix C. The following paragraphs are the specific test objectives:

- Verify the interoperability and compatibility of the OTEC Pilot Plant/On-Shore Electrical Sub-station with the local Electrical Power Grid.
- Verify proper OTEC Pilot Plant operation under abnormal conditions including TBD.
- Verify proper operation of System Safety provisions including TBD.

1.3 Scope of Testing

This Test will be conducted to verify that the OTEC Pilot Plant System and local Electrical Power Grid interface requirements are fulfilled and the OTEC Pilot Plant provides power to the Grid. Additional tests, such as fault tests, will be used to ensure a comprehensive approach to the verification process. Test Configurations are provided in Appendix D.

Outstanding/Open System Trouble Reports are listed in Appendix E. These Trouble Reports (TR) document “known” anomalies that could be observed during the test event.

This Test will be divided into the following events:

Event 1: System Start-Up

This test event will consist of a series of steps necessary to bring the system to an operational state. The Start Up State is defined as TBD.

Event 2: System Operation prior to connection to the On-Shore Substation

This test event will consist of a series of no fault system tests TBD of the Pilot Plant System prior to connecting with the Substation on-shore.

Event 3: System Operation prior to connection to the Electrical Power Grid

This test event will consist of a series of no fault system tests TBD of the Pilot Plant System after connecting with the Substation on-shore but prior to connecting to the local electrical power grid.

Event 4: System Operation when connected to the Electrical Power Grid

This test event will consist of a series of no fault system tests TBD of the Pilot Plant System once connected to the local electrical power grid.

Event 5: Safety Systems

This test event will verify the system safety features of the OTEC Pilot Plant. Hazard monitoring and Fault reporting will be verified in the TBD operating modes.

Event 6: Automated Built-in-Test Equipment (Self-Test)

This test event will verify the BITE capabilities of the OTEC Pilot Plant. Tests will verify the OTEC Pilot Plant Integrated Instrumentation & Control System fault detection and reporting capabilities.

Event 7: Monitoring and Control

This test series will verify the ability of the OTEC Pilot Plant Integrated Instrumentation and Control Segment to detect, process, and react to fault-induced sequences at various points in the operational sequence.

Event 8: System Standby

This test event will consist of a series of steps necessary to bring the system to a Standby state. The Standby State is defined as TBD.

Event 9: System Shut-Down

This test event will consist of a series of steps necessary to bring the system to an Off state. The Off State is defined as TBD.

1.4 Limitations to Scope

This Test includes the interfacing of the Pilot Plant System with the On-Shore Power Station and the Electrical Power Grid System. It does not include Operational Test & Evaluation to be performed during the “pilot” phase once the system has been deployed and is operational.

Due to the nature of system level testing the following assumptions and constraints apply:

- Some system requirements cannot be tested using the system level test configuration. These requirements are tested at lower-level events, such as TBD, using firmware and/or software modified for specific test purposes. Refer to Appendix C for the Requirements Verification Ttaceability Matrix (RVTM) Index for this Test. Refer to the Project RVTM for a complete listing of System/Test requirements and their associated Verification method.
- Tests may be conducted out of sequence as long as they are documented as such.
- Tests may be restructured in order to obtain more detailed test data and will be so documented.
- Special instrumentation may be added as deemed necessary to achieve specific test objectives.
- Tests may be added to better satisfy system test objectives.
- Tests may be deleted as long as they have been conducted under another documented test procedure and test data are available.
- All deviations will be annotated in the Test Procedures and documented in the Test Report.

1.5 Security Requirements

TBD.

2 APPLICABLE/REFERENCED DOCUMENTS

The following documents of the exact issue shown form a part of this document to the extent specified herein.

2.1 Standards

2.1.1 TBS

2.1.2 TBS

2.1.3 TBS

2.2 Ship Specifications

2.2.1 TBS

2.2.2 TBS

2.2.3 TBS

2.3 Contractor Specifications

2.3.1 OTEC Pilot Plant Top Level Requirements

2.3.2 OTEC Pilot Plant CONOPS

2.3.3 OTEC Pilot Plant System Specification (SS)

2.3.4 OTEC Pilot Plant to Grid Interface Control Document (ICD)

2.3.5 OTEC Pilot Plant Platform Substation Subsystem Specification (SSS)

2.3.6 Grid Interface Control Document (ICD)

2.3.7 TBS

2.4 Drawings – Customer

2.4.1 TBS

2.4.2 TBS

2.5 Manuals

2.5.1 TBS

2.6 Other

2.6.1 TBS

3 SYSTEM DESCRIPTION/OVERVIEW

3.1 System/System Hardware

The following paragraphs provide an overview of the various test articles that will form a part of the Test configuration. The exact equipment configuration that will be used for Test is contained in Appendix D.

3.1.1 OTEC Pilot Plant Platform Segment

The Platform is comprised of deck and hull structures. Station-keeping (moorings and anchoring), Electrical plant, Communications & controls, Outfit & furnishing, and auxiliary systems are included as part of this sub-system.

3.1.1.1 Topsides Structure Element

The Topsides Structure consists of upper and lower decks outfitted and furnished with Sub-Systems/Assemblies such as Electrical Plant, Communication and Controls Systems, Safety Systems, and other services.

3.1.1.2 Hull Structure Element

The Hull Structure consists of columns, pontoon, keel and other structural members.

3.1.1.3 Station keeping Element

The Station-keeping sub-system consists of anchoring and mooring systems which keep the Platform at the selected site.

3.1.1.4 Electrical Plant Subsystems

TBS

3.1.1.5 Communications and Control Subsystems

TBS

3.1.1.6 Outfit and Furnishings Subsystems

TBS

3.1.1.7 Auxiliary Systems Subsystems

TBS

3.1.2 OTEC Pilot Plant Power Generation Segment

The Power Generation Segment referred to as a Remora, contains the Heat Exchangers (Evaluators and Condensers), the working fluid (ammonia) sub-system, warm and cold seawater handling sub-systems (ducting, piping, valves & pumps), and the anti- corrosion and anti-bio-fouling sub-systems. These sub-systems are contained within a truss spar structure which is detachable from the Platform.

In addition to the Remora unit the Cold Water Pipe (CWP) is a functionally part of this system but is a separate unit/sub-system. The CWP for the Pilot Plant is a is composite structure, 4m in diameter and approximately 1100 m in length and is constructed in-situ after the platform is on

site. It contains a termination that employs trap-loc technology to allow for secure mounting of the pipe to the platform.

3.1.2.1 Power Cycle Element (Remora)

The Remora (Power Cycle) Element consists of Evaporator and Condenser Heat Exchanger sub-systems. There are 16 cores in the Evaporator assembly which causes the Working Fluid (WF) (ammonia) to boil when heated by the warm surface ocean water producing a vapor to spin the turbine. There are 2 Condenser units which cools the WF vapor and returns it to liquid form so it can be pumped back through the Evaporator.

The Working Fluid (WF) sub-system consists of ammonia storage receptacles (located on deck), interconnect piping, control valves, feed pumps, screens & filters, and anti- corrosion assemblies. The WF passes through the Condenser cooling the ammonia vapor to a liquid to allow circulation through the WF sub-system. The WF is routed from the reservoir via piping through the Heat Exchangers and turbine. This is a closed system. Ammonia storage and sub-system charging takes place from facilities on deck.

The Cold Water (CW) Handling sub-system consists of ducting, piping, valves, pumps, screens & filters, and & anti-bio-fouling assemblies. The CW passes through the Condenser cooling the ammonia vapor to a liquid to allow circulation through the WF sub-system. The CW is routed from the CWP via ducting to the Remora inlet port is piped through the Condensers and is discharged at the lower end of the Remora.

The Warm Water (WW) Handling sub-system consists of ducting, piping, valves anti-corrosion and anti-bio-fouling, screens & filters. The WW passes through the Evaporator heating the ammonia liquid to a vapor. The WW is routed from the WW inlet port piped through the Evaporators and is discharged at the lower end of the Remora.

The Truss Spar structure sub-system consists of Hard and Soft Tanks, Trusses, braces, and equipment foundations/mounting provisions. Provisions for WW storage, Towing, and Handling are also included.

3.1.2.2 Cold Water Pipe Element

The CWP consists of the CWP main body and a Termination section that allows for interfacing and securing to the Platform Hull Structure.

3.1.2.3 Electrical Generation Element

The Turbine sub-system consists of TBS. The turbine is driven by ammonia vapor produced by the Evaporators located inside the Remora. The turbine is connected to one of more electrical generators which produce electricity.

There are two types of generators in this sub-system. The first is the main electrical power Generator(s) connected to the Turbine that produces electricity once the system is operating. The second, for auxiliary power, consists of a start up diesel generator used for the initial start-up of the system and an auxiliary diesel generator as a back-up.

3.1.3 OTEC Pilot Plant Power Delivery Segment

The Power Delivery Segment contains the Turbine & Generators, the electrical power cable to shore (undersea and land portions), the platform substation with the electrical distributions system, and the on-shore electrical substation. The on-shore substation interfaces with the local electrical power grid.

3.1.3.1 Electrical Delivery Element – Platform Substation Subsystem

The Platform substation and electrical power distribution sub-system consists of low and medium voltage sub-systems. The platform substation consists of TBS. The Platform distribution system consists of medium & low voltage power sub-system. The Medium voltage sub-system provides TBS power to the electrical pumps. The Low voltage sub-system provides TBS power for the central control station, system lighting, etc.

3.1.3.2 Electrical Delivery Element – Power Transmission Subsystem

The Electrical Power Transmission cable consists of an undersea portion and an on land portion. It also includes an on shore cable landing vault. These cables TBS.

3.1.3.3 Electrical Delivery Element – Onshore Substation Subsystem

The on-shore electrical substation sub-system consists of TBS. This substation provides the interface between the OTEC Pilot Plant and the local on-shore electrical power grid.

3.1.4 OTEC Pilot Plant Integrated Instrumentation and Control Segment

The Integrated Instrumentation and Control (II&C) Segment provides monitoring and control for the Environmental, Performance, Health/Safety, Security, and Communication sub-sub-systems. A main control center will be the focal point and may include some local control capabilities. Each segment will contain instrumentation and controllers that interface via the main control center.

3.1.4.1 Platform Management

The Platform Control sub-system consists of instrumentation & monitoring equipment, controllers, cabling, electronics cabinets and display consoles, software, and TBS.

The Safety/Health Control sub-system consists of instrumentation & monitoring equipment, controllers, cabling, electronics cabinets and display consoles, software, and TBS.

The Security Control sub-system consists of instrumentation & monitoring equipment, controllers, cabling, electronics cabinets and display consoles, software, and TBS.

The Communication sub-system consists of instrumentation & monitoring equipment, controllers, cabling, electronics cabinets and display consoles, software, and TBS.

3.1.4.2 Power Segments Management

The Power Cycle Instrumentation & Control sub-system consists of instrumentation & monitoring equipment, controllers, cabling, electronics cabinets and display consoles, software, and TBS.

The Cold Water Pipe (CWP) Instrumentation & Control sub-system consists of instrumentation & monitoring equipment, controllers, cabling, electronics cabinets and display consoles, software, and TBS.

The Electrical Generation Instrumentation &Control sub-system consists of instrumentation & monitoring equipment, controllers, cabling, electronics cabinets and display consoles, software, and TBS.

The Electrical Delivery Instrumentation &Control sub-system consists of instrumentation & monitoring equipment, controllers, cabling, electronics cabinets and display consoles, software, and TBS.

3.1.4.3 Environmental Monitoring Management

The Environmental Instrumentation & Control sub-system consists of instrumentation & monitoring equipment, controllers, cabling, electronics cabinets and display consoles, software, and TBS.

3.2 Computer Programs/Software

The following paragraphs provide an overview of the various computer programs that will form a part of the Test configuration. The exact program version/configuration that will be used for Test is contained in Appendix F.

3.2.1 II&C Software Program

TBS

3.2.2 Platform Management Software Program

TBS

3.2.3 Power Generation Management Software Program

TBS

3.2.4 Power Delivery Management Software Program

TBS

3.2.5 Environmental Monitoring Management Software Program

TBS

4 PRODUCT/SYSTEM INTEGRATION ENVIRONMENT

This Interface Test will be conducted on-site, "At Sea" at the Pilot Plant deployment site near Pearl Harbor in Oahu, HI.

During the conduct of this test, particular/peculiar OTEC test equipment will be used to simulate the TBD, record system responses, insert system faults, and provide monitoring and measurements of timing, voltage & current levels, position, temperature, pressure, vibration, shock, and signal levels and waveforms. All test equipment, including applicable standard test tools and OTEC unique/special equipment, shall be calibrated and have calibration stickers that are valid for the duration of the test period.

4.1 Test Facility/Site

The OTEC Pilot Plant site is near Pearl Harbor Oahu, HI. Refer to Figure 4.1-1 for a map showing the location of the OTEC Pilot Plant, Sub-station and Electrical Power Grid.

Figure 4.1-1 OTEC Pilot Plant location map

4.2 Test Equipment

4.2.1 Dummy Load Bank

TBS

4.2.2 Event Data Acquisition System (DAS)

TBS

4.2.3 Environmental Data Acquisition System (EDAS)

TBS

4.2.4 TBD Item 4

TBS

4.2.5 TBD Item 5

TBS

4.2.6 TBD Item 6

TBS

4.2.7 TBD Item 7

TBS

4.2.8 TBD Item 8

TBS

5 TEST PREPARATION AND PARTICIPATING AGENCIES

5.1 Test Preparation/Prerequisites

The following tests/activities are a prerequisite to the start of this Interface Test event:

- Completion of the OTEC Pilot Plant System Integration & Testing (completion of all three phases). This consists completion of the installation and integration of the following:
    - Platform Segment (with Moorings and Anchoring installed and tested).
    - Power Generation System (Remora installation and testing; CWP Fabrication and Deployment).
    - Power Delivery System (Cabling installation and test) testing.
    - Integrated Instrumentation and Control Segment testing.
- Completion of local Electrical Grid System Preparations.
- Completion and Dry Runs of Test Procedures.
- Receipt of all certifications, licenses and operating permits.
- Completion of OTEC Pilot Plant to Grid Interface Test Readiness Review (TRR) and approval to proceed.

5.2 Test Conduct and Location

This Test will be performed at Pilot Plant site near Pearl Harbor Oahu, HI by the OTEC Pilot Plant Integration & Verification Team. All testing shall be conducted at the Pilot Plant site (at sea), at the On-shore Electrical Power Substation, and at local Electrical Power Grid site. All testing shall be performed in accordance with this Test Plan and under direction of an OTEC I&V Team Test Director. Deviations from this Test Plan shall require approval by the OTEC I&V Team Test Director and shall be noted in the Test Procedures and further documented in the Test Report.

5.3 Participating Agencies and Responsibilities

5.3.1 Lockheed Martin– MS2 & SSC

LM-MS2, as the OTEC Team Lead, is responsible for the following:

- Coordination of the development of the Test Plan, Procedures and Report.
- Providing a Test Director and assembling test personnel for the test period.
- Coordination of the facilities/site preparations, Test Equipment, and support equipment for the test event.
- Providing Quality Assurance and Configuration Control of OTEC equipment and software.
- Coordination of data analysis and technical support.
- Coordination of status and quick-look reports.

5.3.2 Lockheed Martin OTEC Team (Partners)

The LM OTEC Team (Partners) are responsible for the following:

- Support of the development of the Test Plan, Procedures and Report.
- Support as test personnel and for technical evaluations for the test period.
- Support of the facilities/site preparations, Test Equipment, and support equipment for the test event.
- Support to Quality Assurance and Configuration Control of OTEC equipment and software.
- Support of data analysis and technical support.
- Support of status and quick-look reports.

5.3.3 United States Navy (USN) Naval Facilities Command (NAVFAC) [Department of Defense (DoD)]

NAVFAC, as the TBD, is responsible for the following:

- Reviewing and approving the Test Plan, Procedures and Report.
- Providing a Test Director and test witnessing for the test period.
- Other

5.3.4 US National Oceanic and Atmospheric Administration (NOAA)

NOAA, as the TBD, is responsible for the following:

- Reviewing and approving the Test Plan, Procedures and Report.
- Providing a Test Director and test witnessing for the test period.
- Other

5.3.5 US Department of Energy (DoE)

The DoE, as the TBD, is responsible for the following:

- Reviewing and approving the Test Plan, Procedures and Report.
- Providing a Test Director and test witnessing for the test period.
- Other

5.3.6 US Environmental Protection Agency (EPA)

The EPA, as the TBD, is responsible for the following:

- Reviewing and approving the Test Plan, Procedures and Report.
- Providing a Test Director and test witnessing for the test period.

- Other

5.4 Test Schedule

Table 5.4-1 - Test Schedule

Activity/Event	Relative to SI&T
Requirements Analysis	220 DPTT
Test Plan (and Test Cases)	200 DPTT
Test Plan *(Peer Review)* Inspection	180 DPTT
Test Plan Release	160 DPTT
Test Procedure (Preliminary)/*(Peer)* Inspection	100 DPTT
Dry Run	90 DPTT
TRR Flip-Through/Trouble Report Critique	60 DPTT
Test Readiness Review	30 DPTT
Test Start	0
Quick Look Analysis	TBD
Debrief	TBD
Test Complete	TBD
Start Final Data Analysis	TBD
Complete Final Data Analysis	60 DATC
Test Procedures (Final) *("As Run")*	60 DATC
Test Report Review	83 DATC
Test Report Delivery	90 DATC

(DPTT = Day Prior To Test; DATC = Days After Test Completion)

6 ANALYSIS PLAN

This section contains the data requirements, planned analyses, evaluation criteria, and reporting requirements.

6.1 Data Collection

For each test conducted during the test period, the following data will be collected:

- Data recordings from TBD**.**
- Data recordings from TBD**.**
- Data files stored on TBD**.**
- Recorded events from the Event Data Acquisition System (DAS) TBD**.**
- Recorded data from the Environmental Data Acquisition System (EDAS) TBD**.**
- Any other test unique measurement (i.e., waveform or strip chart recordings) TBD**.**

The data will be assembled and entered into the test data recording system TBD, identifying the Test ID (run identification number), significant details of the test (from the Test Log), visual observations, and the test outcome.

6.2 Pass/Fail Criteria

The data will be assembled as each individual test is executed. The data collected will be analyzed to verify that test event requirements are satisfied.

Pass or Fail criteria are assessed against each test based on this analysis and comparison with the requirement paragraph cited for each event. This determination takes into account a comparison of the Expected Results with the Actual Results. The Pass/Fail criteria are explained below:

- **Pass** - A test event is considered to "Pass" when the objective(s) of the test is (are) met. All requirements are considered to have been verified.

- **Fail** - A test event is considered to "Fail" when the test objective is not met. The corresponding Trouble Report documents the failure identified with that event. All or some of the requirements may be considered to have not been verified as indicated in the Trouble Report and Test Report.

6.3 Required Reports

6.3.1 Daily Status Reports

Daily Status Reports will be issued and distributed, for each test, reporting test start, test progress and issues, and test completion. This will include anomalies observed during the test and found through data analysis, Trouble Reports generated, and troubleshooting steps.

6.3.2 Quick-Look Reports

A Quick-look Report will be produced and distributed, for each test, prior to the Test De-brief Meeting at the completion of the test. This will include confirmation of the Expected Results both observed during the test and found through data analysis after the test.

6.3.3 Test Report

A Final Test Report will be produced and delivered 90 days after test completion. The test report will include formal test results, data, and data analysis information. Final "As Run" Test Procedures will also be included (scanned, red-lined copy).

7 TEST CASE REQUIREMENTS AND DESCRIPTIONS

This section of the Test Plan outlines the test requirements for the OTEC Pilot Plant to Grid Interface and is presented in contractor format. The individual test event descriptions are structured as follows:

Event Number and Title: This line identifies the name and number of the event.

Event Part Number and Title: This line identifies the name and number of the event part.

1) **Test Objective:** This section provides the objectives of the event. Test requirements from the specified requirements document, will provide the basis for each objective. Specific requirements are referenced for each event; therefore, they are not reiterated in each test description objective.
2) **Special Requirements**: This section provides information specific to each individual test, regarding test configurations, equipment needed, test execution requirements, instrumentation, or other pertinent details.
3) **Data to be Recorded**: This section identifies the type of data recording that will be necessary for this test event/part.
4) **Requirements Cross-Reference**: This section provides the paragraph number of the Requirements documents/specifications (e.g. SS, SSS, SRS, CIDS, PIDS).
5) **Assumptions and Constraints**: This section details test assumptions and limitations relative to setup, conduct, configuration, expected results, and/or deviations, which may be required to execute the event.

7.1 Event 1 – System Start-Up

These tests shall verify the ability of the Pilot Plant to be powered up and brought to an operational state as specified in the TBS requirements.

7.1.1 Event 1 Part 1 - Initial Conditions

1) **Test Objective:**

   Verify the required initial conditions and setting of the Pilot Plant System equipment prior to power-up/light-off as specified in the TBS requirements document.

2) **Special Requirements:**

   Testing will be conducted using the OTEC Pilot Plant Standard Configuration, refer to Appendix D.

3) **Requirements Cross Reference:**

   TBS

4) **Data to be Recorded:**

   a. Data recordings TBD.
   b. Recorded events from the Data Acquisition System (DAS)
   c. Recorded data from the Environmental Data Acquisition System (EDAS)

5) **Assumptions and Constraints:**

   a. TBS

b. TBS
c. TBS

7.1.2 Event 1 Part 2 - Initial Indications

1) Test Objective:

Verify the required initial indications and states of the Pilot Plant System equipment after power-up/light-off as specified in the TBS requirements document.

2) Special Requirements:

Testing will be conducted using the OTEC Pilot Plant Standard Configuration, refer to Appendix D.

3) Cross Reference to Requirements:

TBS

4) Data to be Recorded:

a. Data recordings TBD.
b. Recorded events from the DAS
c. Recorded data from the EDAS

5) Assumptions and Constraints:

a. TBS
b. TBS

7.1.3 Event 1 Part 3 - Standby Operations

1) Test Objective:

Verify the performance of the Pilot Plant System equipment during a Standby Mode of operation as specified in the TBS requirements document.

2) Special Requirements:

Testing will be conducted using the OTEC Pilot Plant Standard Configuration, refer to Appendix D.

3) Cross Reference to Requirements:

TBS

4) Data to be Recorded:

a. Data recordings TBD.
b. Recorded events from the DAS
c. Recorded data from the EDAS

5) Assumptions and Constraints:

a. TBS
b. TBS

7.2 Event 2 – System Operation prior to On-Shore Substation Connection

These tests shall verify the ability of the Pilot Plant to operate in a normal configuration and Mode when not connected to the on-shore substation subsystem as specified in the TBS requirements.

7.2.1 Event 2 Part 1 - TBS

1) Test Objective:

Verify TBS as specified in the TBS requirements document.

2) Special Requirements:

Testing will be conducted using the OTEC Pilot Plant Standard Configuration, refer to Appendix D.

3) Cross Reference to Requirements:

TBS

4) Data to be Recorded:

a. Data recordings TBD.
b. Recorded events from the DAS
c. Recorded data from the EDAS

5) Assumptions and Constraints:

a. TBS
b. TBS

7.2.2 Event 2 Part 2 - TBS

1) Test Objective:

This test shall verify TBS as specified in the TBS requirements document.

2) Special Requirements:

Testing will be conducted using the OTEC Pilot Plant Standard Configuration, refer to Appendix D.

3) Cross Reference to Requirements:

TBS

4) Data to be Recorded:

a. Data recordings TBD.
b. Recorded events from the DAS
c. Recorded data from the EDAS

5) Assumptions and Constraints:

a. TBS
b. TBS

7.2.3 Event 2 Part 3 - TBS

1) Test Objective:

This test shall verify TBS as specified in the TBS requirements document.

2) Special Requirements:

Testing will be conducted using the OTEC Pilot Plant Standard Configuration, refer to Appendix D.

3) Cross Reference to Requirements:

TBS

4) Data to be Recorded:

a. Data recordings TBD.
b. Recorded events from the DAS
c. Recorded data from the EDAS

5) Assumptions and Constraints:

a. TBS
b. TBS

7.3 Event 3 – System Operation prior to local Electrical Power Grid Connection

These tests shall verify the ability of the Pilot Plant to operate in a normal configuration and Mode when connected to the onshore OTEC on-shore substation but prior to connection to the local electrical Power Grid as specified in the TBS requirements.

7.3.1 Event 3 Part 1 - TBS

1) Test Objective:

This test shall verify TBS as specified in the TBS requirements document.

2) Special Requirements:

Testing will be conducted using the OTEC Pilot Plant Standard Configuration, refer to Appendix D.

3) Cross Reference to Requirements:

TBS

4) Data to be Recorded:

a. Data recordings TBD.
b. Recorded events from the DAS
c. Recorded data from the EDAS

5) Assumptions and Constraints:

a. TBS
b. TBS

7.3.2 Event 3 Part 2 - TBS

1) Test Objective:

This test shall verify TBS as specified in the TBS requirements document.

2) Special Requirements:

Testing will be conducted using the OTEC Pilot Plant Standard Configuration, refer to Appendix D.

3) Cross Reference to Requirements:

TBS

4) Data to be Recorded:

a. Data recordings TBD.
b. Recorded events from the DAS
c. Recorded data from the EDAS

5) Assumptions and Constraints:

a. TBS
b. TBS

7.4 Event 4 – System Operation with local Electrical Power Grid Connected

These tests shall verify the ability of the Pilot Plant to operate in a normal configuration and Mode when connected to the local electrical Power Grid and to supply power as requested as specified in the TBS requirements.

7.4.1 Event 4 Part 1 - TBS

1) Test Objective:

This test shall verify TBS as specified in the TBS requirements document.

2) Special Requirements:

Testing will be conducted using the OTEC Pilot Plant Standard Configuration, refer to Appendix D.

3) Cross Reference to Requirements:

TBS

4) Data to be Recorded:

a. Data recordings TBD.
b. Recorded events from the DAS
c. Recorded data from the EDAS

5) Assumptions and Constraints:

a. TBS
b. TBS

7.4.2 Event 4 Part 2 - TBS

1) Test Objective:

This test shall verify TBS as specified in the TBS requirements document.

2) Special Requirements:

Testing will be conducted using the OTEC Pilot Plant Standard Configuration, refer to Appendix D.

3) Cross Reference to Requirements:

TBS

4) Data to be Recorded:

a. Data recordings TBD.
b. Recorded events from the DAS
c. Recorded data from the EDAS

5) Assumptions and Constraints:

a. TBS
b. TBS

7.5 Event 5 – Safety Systems Operation

These tests shall verify the ability of the Pilot Plant to operate or shut-down safely from a normal configuration and Mode when unsafe conditions occur or are detected as specified in the TBS requirements.

7.5.1 Event 5 Part 1 – Hazard Monitoring and Reporting

1) Test Objective:

This test shall verify that Hazardous conditions are detected and reported as specified in the TBS requirements document.

2) Special Requirements:

Testing will be conducted using the OTEC Pilot Plant Standard Configuration, refer to Appendix D.

3) Cross Reference to Requirements:

TBS

4) Data to be Recorded:

a. Data recordings TBD.
b. Recorded events from the DAS
c. Recorded data from the EDAS

5) Assumptions and Constraints:

a. TBS
b. TBS

7.5.2 Event 5 Part 2 – Hazard Controls

1) Test Objective:

This test shall verify that when Hazardous conditions are detected and reported that actions are taken automatically or manually to maintain a safe conditions as specified in the TBS requirements document.

2) Special Requirements:

Testing will be conducted using the OTEC Pilot Plant Standard Configuration, refer to Appendix D.

3) Cross Reference to Requirements:

TBS

4) Data to be Recorded:

a. Data recordings TBD.
b. Recorded events from the DAS
c. Recorded data from the EDAS

5) Assumptions and Constraints:

a. TBS
b. TBS

7.6 Event 6 – Automated Built-in-Test Equipment (BITE) (Self-Test) Operations

These tests shall verify the ability of the Pilot Plant BITE to conduct system surveillance periodically and detect and report system faults or failures as specified in the TBS requirements.

7.6.1 Event 6 Part 1 – Fault Detection and Reporting

1) Test Objective:

This test shall verify that the Self-Test will detect and report system faults or failures as specified in the TBS requirements document.

2) Special Requirements:

Testing will be conducted using the OTEC Pilot Plant Standard Configuration, refer to Appendix D.

3) Cross Reference to Requirements:

TBS

4) Data to be Recorded:

a. Data recordings TBD.
b. Recorded events from the DAS
c. Recorded data from the EDAS

5) Assumptions and Constraints:

a. TBS
b. TBS

7.6.2 Event 6 Part 2 – Fault Corrections and Reporting

1) Test Objective:

This test shall verify that the Self-Test will detect and report system faults or failures that have been corrected and return the system to normal operating conditions as specified in the TBS requirements document.

2) Special Requirements:

Testing will be conducted using the OTEC Pilot Plant Standard Configuration, refer to Appendix D.

3) Cross Reference to Requirements:

TBS

4) Data to be Recorded:

a. Data recordings TBD.
b. Recorded events from the DAS
c. Recorded data from the EDAS

5) Assumptions and Constraints:

a. TBS
b. TBS

7.7 Event 7 – Monitoring and Control Operations

These tests shall verify the ability of the Pilot Plant Integrated Instrumentation and Control (II&C) Segment to conduct system surveillance periodically and detect, record, and report system conditions, data, and measurements as specified in the TBS requirements.

7.7.1 Event 7 Part 1 – Platform Management

1) Test Objective:

This test shall verify that the II&C will detect, record, and report system conditions, data, and measurements for the Platform Management Element as specified in the TBS requirements.

2) Special Requirements:

Testing will be conducted using the OTEC Pilot Plant Standard Configuration, refer to Appendix D.

3) Cross Reference to Requirements:

TBS

4) Data to be Recorded:

a. Data recordings TBD.
b. Recorded events from the DAS
c. Recorded data from the EDAS

5) Assumptions and Constraints:

a. TBS
b. TBS

7.7.2 Event 7 Part 2 – Power Management

1) Test Objective:

This test shall verify that the II&C will detect, record, and report system conditions, data, and measurements for the Power Management Element as specified in the TBS requirements.

2) Special Requirements:

Testing will be conducted using the OTEC Pilot Plant Standard Configuration, refer to Appendix D.

3) Cross Reference to Requirements:

TBS

4) Data to be Recorded:

a. Data recordings TBD.
b. Recorded events from the DAS
c. Recorded data from the EDAS

5) Assumptions and Constraints:

a. TBS
b. TBS

7.7.3 Event 7 Part 3 – Environmental Management

1) Test Objective:

This test shall verify that the II&C will detect, record, and report system conditions, data, and measurements for the Environmental Management Element as specified in the TBS requirements.

2) Special Requirements:

Testing will be conducted using the OTEC Pilot Plant Standard Configuration, refer to Appendix D.

3) Cross Reference to Requirements:

TBS

4) Data to be Recorded:

a. Data recordings TBD.
b. Recorded events from the DAS
c. Recorded data from the EDAS

5) Assumptions and Constraints:

a. TBS
b. TBS

7.8 Event 8 – System Standby Operation

These tests shall verify the ability of the Pilot Plant to operate safely in the Standby Configuration and Mode as specified in the TBS requirements.

7.8.1 Event 8 Part 1 – TBS

1) Test Objective:

This test shall verify TBS as specified in the TBS requirements.

2) Special Requirements:

Testing will be conducted using the OTEC Pilot Plant Standard Configuration, refer to Appendix D.

3) Cross Reference to Requirements:

TBS

4) Data to be Recorded:

a. Data recordings TBD.
b. Recorded events from the DAS
c. Recorded data from the EDAS

5) Assumptions and Constraints:

a. TBS
b. TBS

7.8.2 Event 8 Part 2 – TBS

1) Test Objective:

This test shall verify TBS as specified in the TBS requirements.

2) Special Requirements:

Testing will be conducted using the OTEC Pilot Plant Standard Configuration, refer to Appendix D.

3) Cross Reference to Requirements:

TBS

4) Data to be Recorded:

a. Data recordings TBD.
b. Recorded events from the DAS
c. Recorded data from the EDAS

5) Assumptions and Constraints:

a. TBS
b. TBS

7.9 Event 9 – System Shut-Down Operations

These tests shall verify the ability of the Pilot Plant to safely power down/shut down from a Normal Configuration and Mode as specified in the TBS requirements.

7.9.1 Event 9 Part 1 – Normal Shut down Operation

1) Test Objective:

This test shall verify that the system can safely shut down or be brought off line as specified in the TBS requirements.

2) Special Requirements:

Testing will be conducted using the OTEC Pilot Plant Standard Configuration, refer to Appendix D.

3) Cross Reference to Requirements:

TBS

4) Data to be Recorded:

a. Data recordings TBD.
b. Recorded events from the DAS
c. Recorded data from the EDAS

5) Assumptions and Constraints:

a. TBS
b. TBS

7.9.2 Event 9 Part 2 – Emergency Shut Down Operations

1) Test Objective:

This test shall verify that the system can safely shut down or be brought off line in an Emergency Shut Down situation as specified in the TBS requirements.

2) Special Requirements:

Testing will be conducted using the OTEC Pilot Plant Standard Configuration, refer to Appendix D.

3) Cross Reference to Requirements:

TBS

4) Data to be Recorded:

a. Data recordings TBD.
b. Recorded events from the DAS
c. Recorded data from the EDAS

5) Assumptions and Constraints:

a. TBS
b. TBS

APPENDIX A – Abbreviations & Acronyms

BIT	Built In Test
BITE	Built In Test Equipment
Bio	Biological
CIDS	Critical Item Development Specification
CONOPS	Concept of Operations
CW	Cold Water
CWP	Cold Water Pipe
DAS	Data Acquisition System
DATC	Days After Test Completed
DoD	Department of Defense
DoE	Department of Energy
DPPT	Days Prior To Test
EDAS	Environmental Data Acquisition System
e.g.	for example
EPA	Environmental Protection Agency
HI	Hawai'i
ICD	Interface Control Document
ID	Identification
i.e.	that is
II&C	Integrated Instrumentation & Control
I&C	Instrumentation & Control
I&T	Integration & Test
IT&E	Integration, Test & Evaluation
I&V	Integration & Verification
IV&V	Integration, Verification, and Validation
LM MS2	Lockheed Martin MS2
LM SCC	Lockheed Martin Space System Company
LoB	Line of Business
NAVAC	Naval Facility Engineering Command
NOAA	National Oceanographic and Atmospheric Administration
OTEC	Ocean Thermal Energy Conversion

PIDS	Prime Item Development Specification
RVTM	Requirements Verification Traceability Matrix
SI	System Integration
SI&T	System Integration and Test
SS	System Specification
SSS	Sub-System Specification
SVRM	System Verification Requirements Matrix
TBD	To Be Determined
TBS	To Be Supplied
TR	Trouble Report
TRR	Test Readiness Review
USN	United States Navy
WF	Working Fluid
WW	Warm Water
VRTM	Vacuum Resin Transfer Method

APPENDIX B – Test Schedule & Milestones

TBS

APPENDIX C – Requirements Verification Traceability Matrix (RVTM)

TBS

APPENDIX D – Test Configurations

TBS

APPENDIX E – System Trouble Reports

TBS

APPENDIX F – Software/Computer Program Configurations

TBS

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 4.1-4
OTEC Pilot Plant Monitoring and Controls Matrix Draft
OTEC-2010-001

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OTEC Pilot Plant Monitoring, Instrumentation & Controls Matrix [Draft]

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
PLATFORM	**SYSTEM**	**JHA/HOE**								
			Calculate or measure Sea State [from Design Basis ?]	Measure Sea Conditions: Wave Height Wave Periodicity Currents at selected depths Swells?						
			Calculate or measure Platform Service Life [from Design Basis?]							
			Calculate or measure Platform pitch/roll angles (< 4 deg) [from Design Basis?]							
			Calculate or measure Platform offsets (< 200m) [from Design Basis?]							
			Calculate or measure Platform operations (> 90% condition) [from Design Basis?]	Pitch/roll angles (< 1 deg)						
			Calculate or measure Platform Stress, Strain & Vibration [from Design Basis?]							
			Monitor and measure Control Room characteristics (and for each enclosed space or compartment)	Measure/Monitor: Temperature Humidity Air Flow Air Quality (smoke, etc.)						
			Monitor aircraft movements/approach (monitor helo ops)	Air Search Radar?						
			Monitor surface vessel movements/traffic/approach (monitor small boat ops)	Surface Search Radar?						
			Monitor underwater vessel movements/approach (robots?)	Sonar?						
			Monitor ocean for presence/levels of ammonia in nearby seawater (leaks)	Ammonia sensors						
			Monitor ocean for presence/levels of chlorine in nearby seawater (leaks)	Chlorine sensors						
			Monitor ocean for levels of nitrogen nearby (from CW discharges)	Nitrogen sensors						
			Monitor ocean temperature nearby (from Remora discharges)	Temperature sensors						
			Detect presence/concentration of Ammonia in the air space near the Storage tanks and piping runs	Ammonia vapor sensors						
			Detect presence/concentration of Chlorine in the air space near the Storage tanks and	Chlorine vapor sensors						

OTEC Pilot Plant Monitoring, Instrumentation & Controls Matrix [Draft]

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
			piping runs							
PLATFORM	**TOPSIDES**	**JHA/HOE**								
			Calculate or measure Weather Conditions [from Design Basis ?]	Measure: ? Rain Wind Air Temperature Humidity Barometric Pressure Lightning						
			Visual Monitoring of weather deck operations (Crane, aircraft, water craft, and personnel movements on deck and inside selected spaces & equipment condition) [Monitor safety and security]	Cameras on/off Lighting on/off Boundary alarms & motion or IR sensors						
			Visual Monitoring of lower deck operations (equipment condition and personnel movements on deck and inside selected spaces) [Monitor safety and security]	Cameras on/off Lighting on/off Boundary alarms & motion or IR sensors						
			Detect presence/concentration of Ammonia in Ammonia Storage & Charging compartment							
			Collect Navigation data (IMU reading)	Navigation/ position data						
			Collect Position data (GPS reading)	Position/ location data						
PLATFORM	**HULL**	**JHA/Horton**								
			Calculate or measure Hull Stress, Strain & Vibration [from Design Basis?]							
			Calculate or measure Hull ballast/water levels	Water level sensors; maybe water flow too						
PLATFORM	**STATION KEEPING**	**JHA/SST**								

OTEC Pilot Plant Monitoring, Instrumentation & Controls Matrix [Draft]

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
	Tensioning Subsystem									
			Calculate or measure Tensioning Subsystem Stress, Strain & Vibration [from Design Basis?]							
	Tension Members Subsystem									
			Calculate or measure Tension Members Subsystem Stress, Strain & Vibration [from Design Basis?]							
	Seafloor Anchors Subsystem									
POWER GENERATION	**POWER CYCLE (REMORA)**	**Makai/CB Panchal**								
			Calculate or measure Delta T (≥ 21.6 degC) [from TBS Spec?] {Warm Water inlet temperature less Cold Water inlet temperature – see below}							
			Calculate or measure Remora System Service Life [from Design Basis?]							
			Calculate or measure Remora System (and selected parts) Stress, Strain & Vibration							

OTEC Pilot Plant Monitoring, Instrumentation & Controls Matrix [Draft]

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
			[from Design Basis?]							
	Hull Subsystem									
			Calculate or measure Remora Hull/structure Service Life [from TBS Spec?]							
			Detect presence of water (leaks/flooding) in Remora Hull/structure dry spaces/ compartments							
			Calculate or measure Remora Hull/structure buoyancy/ ballast levels [from TBS Spec?]							
	Ammonia (NH_3) Subsystem									
		E3Tec (CB Panchal)	Safe operating procedure for a range of conditions as well as planned and emergency shutdown.	Normal operation data plus: a) transient data during shutdown/start-up; b) way to monitor leaks.	No specific equipment. Sensors at critical locations.	No		Transient.	Data that can be readily transported to Excel files for analysis.	
		E3Tec (CB Panchal)	Min/Max inventory requirements and transfer of ammonia during normal operation.	Normal operation data plus: a) precise ammonia level in demister, buffer tank and ammonia enclosure; b) estimate of liquid hold-up in evaporators and condensers.	No specific equipment. Sensors at critical locations.	No		Transient.	Data that can be readily transported to Excel files for analysis.	
		E3Tec (CB Panchal)	Testing change-over of ammonia pumps during normal operation.	Transient operating data.	No specific equipment. Sensors at critical locations.	No		Transient.	Data that can be readily transported to Excel files for analysis.	
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Ammonia (Storage) Tank A pressure readings	Ammonia (Storage) Tank A pressure	Pressure meter **P24** (P NH_3 Tank 1 or A)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Ammonia (Storage) Tank B pressure readings	Ammonia (Storage) Tank B pressure	Pressure meter **P25** (P NH_3 Tank 2 or B)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Ammonia (Storage) Tank C pressure readings	Ammonia (Storage) Tank C pressure	Pressure meter **P26** (P NH_3 Tank 3 or C)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect pressure readings to/from Buffer Tank 1 to Auto Purger (2" pipe) – On Platform	Buffer Tank 1 pressure	Pressure meter **P1** (P Buff 1)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect pressure readings from Buffer Tank 1 to input of Condenser 1 (4" pipe)	Buffer Tank 1 pressure	Pressure meter **P3** (P Buff 1 TBD)	TBD				

OTEC Pilot Plant Monitoring, Instrumentation & Controls Matrix [Draft]

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
					Added to list					
		Makai (Pat Grandelli – Ammonia PI&D)	Collect pressure readings to/from Buffer Tank 2 to Auto Purger (2" pipe) – On Platform	Buffer Tank 2 pressure	Pressure meter **P2** (P Buff 2)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect pressure readings from Buffer Tank 2 to input of Condenser 2 (4" pipe)	Buffer Tank 2 pressure	Pressure meter **P4** (P Buff 2 TBD) Added to list	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect pressure readings from output of Condenser 1 to Buffer Tank 1 (18" pipe)	Condenser 1 Ammonia exit pressure	Pressure meter **P6** (P Cond 1 Ex/Out)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect pressure readings at Condenser 1 from Oil Separator System and Turbine Generator (36" pipe)	Condenser 1 Ammonia inlet pressure	Pressure meter **P5** (P Cond 1 In)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect pressure readings from output of Condenser 2 to Buffer Tank 2 (18" pipe)	Condenser 2 Ammonia exit pressure	Pressure meter **P8** (P Cond 2 Ex/Out)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect pressure readings at Condenser 2 from Oil Separator System and Turbine Generator (36" pipe)	Condenser 2 Ammonia inlet pressure	Pressure meter **P7** (P Cond 2 In)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Turbine Generator pressure readings on output side (36" pipe) – On Platform	Turbine Generator output pressure	Pressure meter **P20** (P Turb Out)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Turbine Generator pressure readings on input side (36" pipe) – On Platform	Turbine Generator input pressure	Pressure meter **P19** (P Turb In)	TBD				
		Makai (Pat Grandelli – SW & Ammonia Instr List)	Collect Turbine Generator differential pressure readings (36" pipe) – On Platform	Turbine Generator differential pressure	Pressure meter **P21** (P Turb) ? Not on P&ID	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Ammonia Transfer Pump pressure readings on input side (4" pipe)	Ammonia Transfer Pump input pressure	Pressure gauge **P27** (P TBD In) Added to listed	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Ammonia Transfer Pump pressure readings on output side (4" pipe)	Ammonia Transfer Pump output pressure	Pressure gauge **P28** (P TBD Out) Added to list	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Ammonia Feed Pump Pod 1 pressure readings on input side (18" pipe)	Ammonia Feed Pump Pod 1 input pressure	Pressure meter **P10** (P Pump 1 In)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Ammonia Feed Pump Pod 1 pressure readings on output side (from pump to Evaporator) (18" pipe)	Ammonia Feed Pump Pod 1 output pressure	Pressure meter **P11** (P Pump 1 Out)	TBD				
		Makai (Pat Grandelli –	Collect Ammonia Feed Pump Pod 1 differential pressure readings at strainer (18"	Ammonia Feed Pump Pod 1	Pressure meter /gauge	TBD				

OTEC Pilot Plant Monitoring, Instrumentation & Controls Matrix [Draft]

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
		Ammonia PI&D)	pipe)	Strainer pressure	**P9** (P Strainer 1)					
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Ammonia Feed Pump Pod 2 pressure readings on input side (18" pipe)	Ammonia Feed Pump Pod 2 input pressure	Pressure meter **P13** (P Pump 2 In)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Ammonia Feed Pump Pod 2 pressure readings on output side (from pump to Evaporator) (18" pipe)	Ammonia Feed Pump Pod 2 output pressure	Pressure meter **P14** (P Pump 2 Out)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Ammonia Feed Pump Pod 2 differential pressure readings at strainer (18" pipe)	Ammonia Feed Pump Pod 2 Strainer pressure	Pressure meter /gauge **P12** (P Strainer 2)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect pressure readings to Evaporator input manifold (24" pipe)	Evaporator Ammonia input pressure	Pressure meter **P15** (P Evap In)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect pressure readings from Evaporator (#6) output to Demister Vessel 2 (18" pipe)	Evaporator Ammonia output pressure	Pressure meter **P16** (P Evap Out)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect pressure readings to/from Demister Vessel 1 to Auto Purger (2" pipe)	Demister Vessel 1 pressure	Pressure meter **P17** (P Demis 1)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect pressure readings to/from Demister Vessel 2 to Auto Purger (2" pipe)	Demister Vessel 2 pressure	Pressure meter **P18** (P Demis 1) Added to list	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Ammonia (Storage) Tank A level readings	Ammonia (Storage) Tank A or 1 level	Level sensor **L8** (L NH3 Tank 1)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Ammonia (Storage) Tank B level readings	Ammonia (Storage) Tank B or 2 level	Level sensor **L9** (L NH3 Tank 2)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Ammonia (Storage) Tank C level readings	Ammonia (Storage) Tank C or 3 level	Level sensor **L10** (L NH3 Tank 3)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Ammonia Buffer Tank 1A level readings	Buffer Tank 1A level	Level sensor **L1** (L Buff 1a)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Ammonia Buffer Tank 1B level readings	Buffer Tank 1B level	Level sensor **L2** (L Buff 1b)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Ammonia Buffer Tank 2A level readings	Buffer Tank 2A level	Level sensor **L3** (L Buff 2a)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Ammonia Buffer Tank 2B level readings	Buffer Tank 2B level	Level sensor **L4** (L Buff 2b)	TBD				

OTEC Pilot Plant Monitoring, Instrumentation & Controls Matrix [Draft]

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Ammonia Demister Vessel 1 level readings	Demister Vessel 1 level	Level sensor **L5** (L Demis 1 or a)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Ammonia Demister Vessel 2 level readings	Demister Vessel 2 level	Level sensor **L6** (L Demis 2 or b)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Turbine Generator temperature readings on output side (36" pipe) – On Platform	Turbine Generator output temperature	Temperature meter **T16** (T Turb Out)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Turbine Generator temperature readings on input side (36" pipe) – On Platform	Turbine Generator input temperature	Temperature meter **T15** (T Turb In)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect temperature readings to/from Buffer Tank 1 (A – TBS)	Buffer Tank 1A temperature	Temperature meter **T1** (T Buff 1a)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect temperature readings to/from Buffer Tank 1 (B – TBS)	Buffer Tank 1B temperature	Temperature meter **T2** (T Buff 1b)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect temperature readings to/from Buffer Tank 2 (A – TBS)	Buffer Tank 2A temperature	Temperature meter **T3** (T Buff 2a)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect temperature readings to/from Buffer Tank 2 (B – TBS)	Buffer Tank 2B temperature	Temperature meter **T4** (T Buff 2b)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect temperature readings at Condenser 1 input (36" pipe)	Condenser 1 Ammonia inlet temperature	Temperature meter **T5** (T Cond 1 In)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect temperature readings at Condenser 1 output (36" pipe)	Condenser 1 Ammonia exit temperature	Temperature meter **T6** (T Cond 1 Ex/Out)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect temperature readings at Condenser 2 input (36" pipe)	Condenser 2 Ammonia inlet temperature	Temperature meter **T7** (T Cond 2 In)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect temperature readings at output of Condenser 2 (36" pipe)	Condenser 2 Ammonia exit temperature	Temperature meter **T8** (T Cond 2 Ex/Out)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Ammonia Feed Pump Pod 1 temperature readings at output (Evaporator side) (18" pipe)	Ammonia Pump Pod 1 output temperature	Temperature meter **T9** (T Pump 1 Out)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Ammonia Feed Pump Pod 2 temperature readings at output (Evaporator side) (18" pipe)	Ammonia Transfer Pump Pod 2 output temperature	Temperature meter **T10** (T Pump 2 Out)	TBD				
		Makai (Pat Grandelli –	Collect Evaporator input manifold temperature reading (24" pipe)	Evaporator Ammonia input manifold temperature	Temperature meter **T11** (T Evap In)	TBD				

OTEC Pilot Plant Monitoring, Instrumentation & Controls Matrix [Draft]

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		Ammonia PI&D)								
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Evaporator (#6 to Demister 2) ouput temperature reading (18" pipe)	Evaporator Ammonia output temperature	Temperature meter **T12** (T Evap Out)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect temperature readings to/from Demister Vessel 1	Demister Vessel 1 temperature	Temperature meter **T13** (T Demis 1)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect temperature readings to/from Demister Vessel 2	Demister Vessel 2 temperature	Temperature meter **T14** (T Demis 2) Added to list	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect mass flow meter readings for Ammonia (TBS" pipe) – On Platform	Ammonia Makeup mass flow	Flow meter **M7** (M Makeup NH3)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect flow meter readings from Ammonia Feed Pump Pod 1 to Evaporators (18" pipe)	Ammonia Feed Pump Pod 1 flow to Evaporator manifold	Flow meter **M1** (M/F Pump 1 Out)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect flow meter readings from Ammonia Feed Pump Pod 2 to Evaporators (18" pipe)	Ammonia Feed Pump Pod 2 flow to Evaporator manifold	Flow meter **M2** (M Pump 2 Out)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect flow meter readings from Demister Vessel 1 to Evaporator (12" pipe)	Demister Vessel 1 flow to Evaporator manifold	Flow meter **M3** (M Recirc/Demis 1)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect flow meter readings from Demister Vessel 2 to Evaporator (12" pipe)	Demister Vessel 2 flow to Evaporator manifold	Flow meter **M4** (M Recirc/Demis 2) Added to list	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect mass flow meter readings for Turbine input (36" pipe) – On Platform	Turbine input mass flow	Mass Flow meter **M5** (M Turb In)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect mass flow meter readings for Turbine bypass (TBS" pipe) – On Platform	Turbine Bypass mass flow	Mass Flow meter **M6** (M Turb By)	TBD				
		Makai (Pat Grandelli – SW & Ammonia Instr List)	Collect turbine trip valve readings (TBS" pipe) – On Platform	Turbine trip valve	Trip Valve meter **N1** (? Ammonia) ? Not on P&ID	TBD				
		Makai (Pat Grandelli – SW & Ammonia Instr List)	Collect speed readings from Pump Pod 1 VFD (18" pipe) – On Platform	Ammonia Feed Pump Pod 1 flow to Evaporator manifold	Tachometer **S1** (S Pump 1) Not on P&ID	TBD				
		Makai (Pat Grandelli – SW & Ammonia Instr List)	Collect speed readings from Pump Pod 2 VFD (18" pipe) – On Platform	Ammonia Feed Pump Pod 2 flow to Evaporator manifold	Tachometer **S2** (S Pump 2) Not on P&ID	TBD				

OTEC Pilot Plant Monitoring, Instrumentation & Controls Matrix [Draft]

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
			Calculate or measure Ammonia Flow Rate (167X2 – 200X2 kg/sec) [from Remora Spec?]							
			Collect Ammonia pump bearing temperature readings							
			Collect Ammonia pump bearing vibration readings							
			Detect presence/concentration of Ammonia in TBD							
			Collect Ammonia pump supply voltage readings							
			Collect Ammonia pump supply current readings							
	Heat Exchanger Subsystem (Evaporator)									
		E3Tec (CB Panchal)	Validation of thermal and hydraulic performance.	Accurate time-average measurements of flow rates, pressures and temperatures.						
		E3Tec (CB Panchal)	Interactive transient responses with ammonia turbine and seawater pumps.	Transient measurements of the power cycle system parameters and external/environmental parameters (e.g., prevailing wave heights, grid-power fluctuations)						
		E3Tec (CB Panchal)	Seasonal variation of rate of corrosion and bio-fouling and effectiveness of bio-fouling control.	Fouling rate on daily basis.	Fouling monitoring unit.	No				
		E3Tec (CB Panchal)	Correlating fouling (corrosion and bio-fouling) with the heat exchanger performance.	Fouling monitoring unit plus process parameters to accurately calculate the overall heat transfer coefficient.						
		E3Tec (CB Panchal)	Monitoring of corrosion of aluminum heat exchangers: internal and external.	Observation of severe pitting corrosion.	Monitoring camera in the water header and outside plus manual observation, if possible.	Yes				
			Calculate or measure Heat Exchanger (Evaporator) temperature in (< 25.7 degC) [from Remora Spec?]							
			Calculate or measure Heat Exchanger (Evaporator) temperature out (< 23.0 degC) [from Remora Spec?]							

OTEC Pilot Plant Monitoring, Instrumentation & Controls Matrix [Draft]

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
			Calculate or measure Evaporator Service Life [from TBS Spec?]							
			Detect concentration levels of Ammonia in Ammonia piping (warm water leaks)							
			Detect presence/concentration of Chlorine in Ammonia piping from the Hx							
	Warm Water Subsystem									
		E3Tec (CB Panchal)	Pump flow characteristics as a function of environmental conditions: wave heights & frequency; currents (direction & intensity); temperatures.	Transient flow rates and pressure measurements at selected locations during significant environmental conditions.	Flow meters, pressure sensors, pump power, and RPM.	No				
		E3Tec (CB Panchal)	Bio-fouling characteristics	Routine water chemistry						
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Warm water differential pressure readings at Evaporator (TBD" pipe)	Warm water Evaporator differential pressure (inlet to outlet)	Pressure meter **P29** (P Evap WW) Not on P&ID	TBD				
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Warm water differential pressure readings at inlet screen (TBD" pipe)	Warm water Inlet Screen differential pressure	Pressure meter **P30** (P Screen WW) Not on P&ID	TBD				
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Warm water differential pressure readings from inlet to discharge (TBD" pipe)	Warm water Inlet to Discharge differential pressure	Pressure meter **P31** (P WW) Not on P&ID	TBD				
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Warm Water pump seal oil pressure readings – On Platform	WW Pump Oil Seal Pressure	Pressure meter **P32** (P Seal WW) ? Not on P&ID	TBD				
		Makai (Pat Grandelli – Ammonia P& ID)	Collect Warm water temperature readings from Evaporator #1 input (from manifold) (TBS" pipe)	Evaporator #1 Warm water input temperature	Temperature meter **T17** (T Evap 1 WW In)	TBD				
		Makai (Pat Grandelli – Ammonia P& ID)	Collect Warm water temperature readings from Evaporator #1 output (to Demisters) (TBS" pipe)	Evaporator #1 Warm water output temperature	Temperature meter **T23** (T Evap 1 WW Out)	TBD				
		Makai (Pat Grandelli – Ammonia P& ID)	Collect Warm water temperature readings from Evaporator #2 input (from manifold) (TBS" pipe)	Evaporator #2 Warm water input temperature	Temperature meter **T18** (T Evap 2 WW In)	TBD				
		Makai (Pat Grandelli – Ammonia P& ID)	Collect Warm water temperature readings from Evaporator #2 output (to Demisters) (TBS" pipe)	Evaporator #2 Warm water output temperature	Temperature meter **T24** (T Evap 2 WW Out)	TBD				

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SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
		Makai (Pat Grandelli – Ammonia P& ID)	Collect Warm water temperature readings from Evaporator #3 input (from manifold) (TBS" pipe)	Evaporator #3 Warm water input temperature	Temperature meter **T19** (T Evap 3 WW In)	TBD				
		Makai (Pat Grandelli – Ammonia P& ID)	Collect Warm water temperature readings from Evaporator #3 output (to Demisters) (TBS" pipe)	Evaporator #3 Warm water output temperature	Temperature meter **T25** (T Evap 3 WW Out)	TBD				
		Makai (Pat Grandelli – Ammonia P&ID)	Collect Warm water temperature readings from Evaporator #4 input (from manifold) (TBS" pipe)	Evaporator #4 Warm water input temperature	Temperature meter **T20** (T Evap 4 WW In)	TBD				
		Makai (Pat Grandelli – Ammonia P&ID)	Collect Warm water temperature readings from Evaporator #4 output (to Demisters) (TBS" pipe)	Evaporator #4 Warm water output temperature	Temperature meter **T26** (T Evap 4 WW Out)	TBD				
		Makai (Pat Grandelli – Ammonia P&ID)	Collect Warm water temperature readings from Evaporator #5 input (from manifold) (TBS" pipe)	Evaporator #5 Warm water input temperature	Temperature meter **T21** (T Evap 5 WW In)	TBD				
		Makai (Pat Grandelli – Ammonia P&ID)	Collect Warm water temperature readings from Evaporator #5 output (to Demisters) (TBS" pipe)	Evaporator #5 Warm water output temperature	Temperature meter **T27** (T Evap 5 WW Out)	TBD				
		Makai (Pat Grandelli – Ammonia P&ID)	Collect Warm water temperature readings from Evaporator #6 input (from manifold) (TBS" pipe)	Evaporator #6 Warm water input temperature	Temperature meter **T22** (T Evap 6 WW In)	TBD				
		Makai (Pat Grandelli – Ammonia P&ID)	Collect Warm water temperature readings from Evaporator #6 output (to Demisters) (TBS" pipe)	Evaporator #6 Warm water output temperature	Temperature meter **T28** (T Evap 6 WW Out)	TBD				
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Warm water pump temperature readings	Warm water pump temperature	Temperature meter **T29** (T Pump WW) Not on P&ID	TBD				
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Warm water flow readings from/to TBS (TBS" pipe)	Warm water flow TBS	Flow meter **M9** (M WW 1) Not on P&ID	TBD				
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Warm water flow readings from /to TBS (TBS" pipe)	Warm water flow TBS	Flow meter **M10** (M WW 2) Not on P&ID	TBD				
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Warm water pump speed readings – On Platform	Warm water pump speed (VFD)	Speed/Frequency meter **S4** (S Pump WW) Not on P&ID	TBD				
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Warm water pump current readings – On Platform	Warm water pump current	Amperage meter **C2** (C Pump WW) Not on P&ID	TBD				

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		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Warm water pump vibration readings	Warm water pump vibration	Vibration meter **V2** (V Pump WW) Not on P&ID	TBD				
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Warm Water inlet camera (lighting too?)	WW inlet visual	Underwater Camera **O1** (O Pump WW In) ? Not on P&ID	TBD				
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Warm Water inlet ammonia readings – On Platform	WW inlet ammonia leak detection	Ammonia sensor **D1** (? Ammonia WW In) ? Not on P&ID	TBD				
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Warm Water discharge ammonia readings	WW discharge ammonia leak detection from Evaporator (outlet or exit)	Ammonia sensor **D2** (? Ammonia WW Dis/Out) ? Not on P&ID	TBD				
		Makai (Pat Grandelli - SW & Ammonia Inst List)	Collect Warm Water discharge chlorine readings	WW discharge chlorine level detection from anti-biofouling system (outlet or exit)	Chlorine sensor **D3** (? Chlorine WW Dis/Out) ? Not on P&ID	TBD				
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Warm Water anti-biofouling readings TBD	WW anti-biofouling TBD	**D4** TBD Not on P&ID	TBD				
			Calculate or measure (Warm) Water Intake Screen velocity (< 0.15 m/sec) [from Remora Spec]							
			Calculate or measure Warm Water Discharge velocity/speed (< 1.2 m/sec) [from Remora Spec?]							
			Calculate or measure Warm Water Discharge temperature (TBD degC) [from Remora Spec?]							
			Calculate or measure Warm Water inlet temperature (25.7 ± TBD degC) [from Remora Spec?]							
			Calculate or measure Warm Water Flow Rate (46.2 ± TBD m/sec) [from Remora Spec?]							
			Collect Warm Water pump bearing temperature readings							
			Collect Warm Water pump bearing vibration readings							

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			Detect presence/concentration of Ammonia in Warm water piping							
			Detect presence/concentration of Chlorine in Warm water piping							
			Collect Warm water pump supply voltage readings							
			Collect Warm water pump supply current readings							
	Heat Exchanger Subsystem (Condenser)									
		E3Tec (CB Panchal)	Validation of thermal and hydraulic performance.	Accurate time-average measurements of flow rates, pressures and temperatures.						
		E3Tec (CB Panchal)	Interactive transient responses with ammonia turbine and seawater pumps.	Transient measurements of the power cycle system parameters and external/environmental parameters (e.g., prevailing wave heights, grid-power fluctuations)						
		E3Tec (CB Panchal)	Seasonal variation of rate of corrosion and bio-fouling and effectiveness of bio-fouling control.	Fouling rate on daily basis.	Fouling monitoring unit.	No				
		E3Tec (CB Panchal)	Correlating fouling (corrosion and bio-fouling) with the heat exchanger performance.	Fouling monitoring unit plus process parameters to accurately calculate the overall heat transfer coefficient.						
		E3Tec (CB Panchal)	Monitoring of corrosion of aluminum heat exchangers: internal and external.	Observation of severe pitting corrosion.	Monitoring camera in the water header and outside plus manual observation, if possible.	Yes				
			Calculate or measure Heat Exchanger (Condenser) temperature in (< 4.1 degC) [from Remora Spec?]							
			Calculate or measure Heat Exchanger (Condenser) temperature out (< 7.4 degC) [from Remora Spec?]							
			Calculate or measure Condenser Service Life [from TBS Spec?]							
	Cold Water Subsystem									

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		E3Tec (CB Panchal)	Pump flow characteristics as a function of environmental conditions: wave heights & frequency; currents (direction & intensity); temperatures.	Transient flow rates and pressure measurements at selected locations during significant environmental conditions.	Flow meters, pressure sensors, pump power, and RPM.	No				
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Cold water pump inlet pressure readings (TBD" pipe)	Cold water pump inlet pressure	Pressure meter **P37** (P Pump CW In) Not on P&ID	TBD				
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Cold water differential pressure readings at pump inlet to discharge (TBD" pipe)	Cold water pump differential pressure (inlet to discharge)	Pressure meter **P33** (P Pump CW) Not on P&ID	TBD				
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Cold water differential pressure readings from termination to elbow (TBD" pipe)	Cold water pipe termination to elbow differential pressure	Pressure meter **P34** (P Term CW) Not on P&ID	TBD				
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Cold water differential pressure readings from conduit inlet to outlet (TBD" pipe)	Cold water conduit Inlet to Outlet differential pressure	Pressure meter **P35** (P CW) Not on P&ID	TBD				
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Cold Water pump seal oil pressure readings – On Platform	CW Pump Oil Seal Pressure	Pressure meter **P36** (P Seal CW) ? Not on P&ID	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Cold water temperature readings at input end of Condenser 1	Condenser 1 Cold water temperature (inlet side)	Temperature meter **T30** (T Cond 1 CW In)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Cold water temperature readings at output end of Condenser 1	Condenser 1 Cold water temperature (exit side)	Temperature meter **T31** (T Cond 1 CW Ex/Out)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Cold water temperature readings at input end of Condenser 1	Condenser 2 Cold water temperature (inlet side)	Temperature meter **T32** (T Cond 2 CW In)	TBD				
		Makai (Pat Grandelli – Ammonia PI&D)	Collect Cold water temperature readings at output end of Condenser 1	Condenser 2 Cold water temperature (exit side)	Temperature meter **T33** (T Cond 2 CW Ex/Out)	TBD				
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Cold water pump temperature readings	Cold water pump temperature	Temperature meter **T34** (T Pump CW) Not on P&ID	TBD				
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Cold water flow readings from/to TBS (TBS" pipe)	Cold water flow TBS	Flow meter **M11** (M CW 1) Not on P&ID	TBD				

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		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Cold water flow readings from /to TBS (TBS" pipe)	Cold water flow TBS	Flow meter **M12** (M CW 2) Not on P&ID	TBD				
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Cold water pump speed readings – On Platform	Cold water pump speed (VFD)	Speed/Frequency meter **S5** (S Pump CW) Not on P&ID	TBD				
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Cold water pump current readings – On Platform	Cold water pump current	Amperage meter **C3** (? Pump CW) Not on P&ID	TBD				
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Cold water pump vibration readings	Cold water pump vibration	Vibration meter **V3** (V Pump CW) Not on P&ID	TBD				
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Cold Water inlet camera (lighting too?)	CW inlet visual	Underwater Camera **O2** (O Pump CW In) ? Not on P&ID	TBD				
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Cold Water inlet ammonia readings – On Platform	CW inlet ammonia leak detection	Ammonia sensor D5 (? Ammonia CW In) ? Not on P&ID	TBD				
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Cold Water discharge ammonia readings	CW discharge ammonia leak detection from Evaporator (outlet or exit)	Ammonia sensor D6 (? Ammonia CW Dis/Out) ? Not on P&ID	TBD				
		Makai (Pat Grandelli - SW & Ammonia Inst List)	Collect Cold Water discharge chlorine readings	CW discharge chlorine level detection from anti-biofouling system (outlet or exit)	Chlorine sensor D7 (? Chlorine CW Dis/Out) ? Not on P&ID	TBD				
		Makai (Pat Grandelli – SW & Ammonia Inst List)	Collect Cold Water anti-biofouling readings TBD	CW anti-biofouling TBD	D8 (TBD) Not on P&ID	TBD				
			Calculate or measure Water Intake Screen velocity (< 0.15 m/sec)?[from Remora Spec]							
			Calculate or measure Cold Water Discharge velocity/speed (< 1 m/sec) [from Remora Spec?]							
			Calculate or measure Cold Water Discharge temperature (TBD degC) [from Remora Spec?]							

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			Calculate or measure Cold Water Inlet temperature (4.1 ± TBD degC) [from Remora Spec?]							
			Calculate or measure Cold Water Flow Rate (32 ± TBD m/sec) [from Remora Spec?]							
			Collect Cold Water pump bearing temperature readings							
			Collect Cold Water pump bearing vibration readings							
			Detect presence/concentration of Ammonia in Cold water piping							
			Collect Cold water pump supply voltage readings							
			Collect Cold water pump supply current readings							
POWER GENERATION	**COLD WATER PIPE (CWP)**	**Makai/LM-SSC**								
	Pipe Subsystem	LM-SSC/ Makai								
			Calculate or measure CWP Service Life [from TBS Spec?]							
			Calculate or measure maximum composite strain (< 1%) [from TBS Spec?]							
			Calculate or measure CWP Stress, Strain & Vibration [from Design Basis?]	Strain gages						
			Monitor/ Measure CWP inlet temperature							
			Monitor/ Measure CWP pressure							
			Monitor/ Measure CW Duct (on Platform) inlet temperature							
	Connection Subsystem (Platform Mounting)	LM-SSC/ Makai								

OTEC Pilot Plant Monitoring, Instrumentation & Controls Matrix [Draft]

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
	Termination Subsystem (w/Gimbal?)	LM-SSC/ Makai								
POWER GENERATION	**ELECTRICAL GENERATION**	**Makai/LM-MS2**								
			Calculate or measure Average Net Power (5 MWe) [from Sys Spec]							
			Calculate or measure T-G Stress, Strain & Vibration [from Design Basis?]							
			Calculate or measure Steady State Operations (2 MW min. – 1 MW min. evening) [from Electrical Generation Spec?]							
			Calculate or measure Steady State Operations (0.8 < V < 1.1 pu) [from Electrical Generation Spec?]							
			Monitor and measure T-G spaces /compartment characteristics	Measure/Monitor: Temperature Humidity Air Flow Air Quality (presence of smoke, ammonia, etc.)						
	Turbine Subsystem	LM-MS2/Makai								
		Makai (Pat Grandelli /Jim Hurtt from SW & Ammonia Instr List)	Collect turbine bypass valve position readings (TBS" pipe) – On Turbine-Generator Skid	Turbine by-pass valve position	Position gage/meter **N2** (? Turb) ?	TBD				
		Makai (Pat Grandelli /Jim Hurtt from SW & Ammonia Instr List)	Collect turbine vibration readings (TBS" pipe) – On Turbine-Generator Skid	Turbine vibration at each bearing	Vibration gage/meter **V1** (V Turb) ?	TBD				
		Makai (Pat Grandelli /Jim	Collect turbine speed/frequency readings – On Turbine-Generator Skid	Turbine Speed	Frequency meter/Tachometer ? (rpm or	TBD				

OTEC Pilot Plant Monitoring, Instrumentation & Controls Matrix [Draft]

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
		Hurtt from SW & Ammonia Instr List)			rad/sec) **S3** (S Turb TBS) ?					
		Makai (Pat Grandelli /Jim Hurtt from SW & Ammonia Instr List)	Collect seal oil buffer pressure readings – On Turbine-Generator Skid	Seal Oil Buffer Pressure	Pressure meter **P23** (P Seal TBS) ?	TBD				
		Makai (Pat Grandelli /Jim Hurtt from SW & Ammonia Instr List)	Collect lube oil level readings – On Lube Oil Skid	Lube Oil Level	Level sensor **L7** (L Oil TBS) ?	TBD				
		Makai (Pat Grandelli /Jim Hurtt from SW & Ammonia Instr List)	Collect lube oil pressure readings – On Lube Oil Skid	Lube Oil Pressure	Pressure meter **P22** (P Oil TBS) ?	TBD				
		Makai (Pat Grandelli /Jim Hurtt from SW & Ammonia Instr List)	Collect Turbine-Generator Room ventilation system readings	Ventilation	Ventilation meter **H1** (? T-G HVAC TBS) ?	TBD				
			Calculate or measure Turbine power output (5MW ave.; 8.7 MW max.) [from Electrical Generation Spec?]							
			Calculate or measure Turbine inlet pressure (912 kPa max.) [from Electrical Generation Spec?]							
			Calculate or measure Turbine mass flow rate (< 212 kg/sec.) [from Electrical Generation Spec?]							
			Calculate or measure Turbine Service Life [from TBS Spec?]							
			Calculate or measure Turbine Vibration [from Design Basis?]							
			Collect Turbine bearing temperature readings							
			Collect Turbine bearing vibration readings							
	Generator Subsystem	LM-MS2/Makai								
		Makai (Pat Grandelli /Jim Hurtt from SW &	Collect generator speed/frequency readings – On Turbine-Generator Skid	Generator Frequency	Frequency meter **F1** (F Gen TBS) ?	TBD				

OTEC Pilot Plant Monitoring, Instrumentation & Controls Matrix [Draft]

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
		Ammonia Instr List)								
		Makai (Pat Grandelli /Jim Hurtt from SW & Ammonia Instr List)	Collect generator voltage readings – On Turbine-Generator Skid	Generator Voltage	Voltage meter **E1** (V Gen TBS) ?	TBD				
		Makai (Pat Grandelli /Jim Hurtt from SW & Ammonia Instr List)	Collect generator current readings – On Turbine-Generator Skid	Generator Current	Amperage meter **C1** (C Gen TBS) ?	TBD				
		Makai (Pat Grandelli /Jim Hurtt from SW & Ammonia Instr List)	Collect generator power readings – On Turbine-Generator Skid	Generator Power	Power meter **K1** (? Gen TBS) ?	TBD				
		Makai (Pat Grandelli /Jim Hurtt from SW & Ammonia Instr List)	Collect generator circuit position readings – On Turbine-Generator Skid	Generator Circuit Breaker position	Position meter **N3** (? Gen TBS) ?	TBD				
		Makai (Pat Grandelli /Jim Hurtt from SW & Ammonia Instr List)	Collect generator flame readings – On Turbine-Generator Skid	Generator Flame	Flame sensor **U1** (? Gen TBS) ?	TBD				
			Collect generator speed/frequency readings – On Turbine-Generator Skid	Generator Speed	Frequency meter/Tachometer ? (rpm or rad/sec) **S4** (S Gen TBS) ?					
			Calculate or measure Generator frequency (60 ± 0.1 Hz) [from Electrical Generation Spec?]							
			Calculate or measure Generator power (13.8 KV L-L ± TBD) [from Electrical Generation Spec?]							
			Calculate or measure characteristics to comply with HECO Power Flow Regulations [from Electrical Generation Spec?]							
			Calculate or measure characteristics to comply with ANSI/NEMA Electrical Standards [from Electrical Generation Spec?]							
			Calculate or measure Operational Transients (1 MW/2 sec or 0.3 MW/2sec) [from							

OTEC Pilot Plant Monitoring, Instrumentation & Controls Matrix [Draft]

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
			Electrical Generation Spec?]							
			Calculate or measure Generator Service Life [from TBS Spec?]							
			Calculate or measure Generator Vibration [from Design Basis?]							
			Collect Generator bearing temperature readings							
			Collect Generator bearing vibration readings							
			Collect Generator output voltage readings							
			Collect Generator output current readings							
POWER DELIVERY	**ELECTRICAL DELIVERY**	**LM-MS2**								
	Platform Substation Subsystem	LM-MS2								
	On-Shore Substation Subsystem	LM-MS2								
	Power Transmission Subsystem (Cabling & Shore Landing Vault)	LM-MS2								
			Calculate or measure Power transmission Cable Stress, Strain & Vibration [from Design Basis?]							

OTEC Pilot Plant Monitoring, Instrumentation & Controls Matrix [Draft]

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
INTEGRATED INSTRUMENTATION & CONTROL	**PLATFORM MANAGEMENT**	**LM-MS2**								
	Platform I&C Subsystem	LM-MS2								
	Safety, Security & Communications I&C Subsystem									
INTEGRATED INSTRUMENTATION & CONTROL	**POWER (CYCLE) MANAGEMENT**	**LM-MS2**								
	Power Cycle (Remora) I&C Subsystem									
	CWP I&C Subsystem									
	Electrical Generation									

OTEC Pilot Plant Monitoring, Instrumentation & Controls Matrix [Draft]

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
	I&C Subsystem									
	Electrical Delivery I&C Subsystem									
INTEGRATED INSTRUMENTATION & CONTROL	**ENVIRONMENTAL MONITORING MANAGEMENT**	**LM-MS2**								
	Environmental I&C Subsystem									

OTEC Pilot Plant Monitoring, Instrumentation & Controls Matrix [Draft]

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM

NAVFAC Ocean Thermal Energy Conversion (OTEC) Project

Contract Number N62583-09-C-0083

CDRL A003
OTEC System Design Report
Appendix 4.1-5
OTEC Pilot Plant Operational Test Matrix Draft
OTEC-2010-001

17 September 2010

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OTEC Pilot Plant Operational Testing Matrix [Draft] (special test equipment needs)

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	ADDITIONAL PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
			Calculate or measure Sea State [from Design Basis ?]	Measure Sea Conditions: Wave Height Wave Periodicity Currents at selected depths Swells?						
			Calculate or measure Platform Service Life [from Design Basis?]							
			Calculate or measure Platform pitch/roll angles (< 4 deg) [from Design Basis?]							
			Calculate or measure Platform offsets (< 200m) [from Design Basis?]							
			Calculate or measure Platform operations (> 90% condition) [from Design Basis?]	Pitch/roll angles (< 1 deg)						
			Calculate or measure Platform Stress, Strain & Vibration [from Design Basis?]							
			Monitor and measure Control Room characteristics (and for each enclosed space or compartment)	Measure/Monitor: Temperature Humidity Air Flow Air Quality (smoke, etc.)						
			Monitor aircraft movements/approach (monitor helo ops)	Air Search Radar?						
			Monitor surface vessel movements/traffic/approach (monitor small boat ops)	Surface Search Radar?						
			Monitor underwater vessel movements/approach (robots?)	Sonar?						
			Monitor ocean for presence/levels of ammonia nearby (leaks)							
			Monitor ocean for levels of nitrogen nearby (from CW discharges)							
			Monitor ocean temperature nearby (from Remora discharges)							
PLATFORM	**TOPSIDES**	**JHA/HOE**								
			Calculate or measure Weather Conditions [from Design Basis ?]	Measure?: Rain Wind Air Temperature Humidity						

OTEC Pilot Plant Operational Testing Matrix [Draft] (special test equipment needs)

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	ADDITIONAL PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
				Barometric Pressure						
			Visual Monitoring of weather deck operations (Crane, aircraft, water craft, and personnel movements on deck and inside selected spaces & equipment condition) [Monitor safety and security]	Cameras on/off Lighting on/off Boundary alarms & motion or IR sensors						
			Visual Monitoring of lower deck operations (equipment condition and personnel movements on deck and inside selected spaces) [Monitor safety and security]	Cameras on/off Lighting on/off Boundary alarms & motion or IR sensors						
PLATFORM	**HULL**	**JHA/Horton**								
			Calculate or measure Hull Stress, Strain & Vibration [from Design Basis?]							
PLATFORM	**STATION KEEPING**	**JHA/SST**								
	Tensioning Subsystem									
			Calculate or measure Tensioning Subsystem Stress, Strain & Vibration [from Design Basis?]							

OTEC Pilot Plant Operational Testing Matrix [Draft] (special test equipment needs)

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	ADDITIONAL PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
	Tension Members Subsystem									
			Calculate or measure Tension Members Subsystem Stress, Strain & Vibration [from Design Basis?]							
	Seafloor Anchors Subsystem									
POWER GENERATION	**POWER CYCLE (REMORA)**	**Makai/CB Panchal**								
			Calculate or measure Delta T (≥ 21.6 degC) [from TBS Spec?] {Warm Water inlet temperature less Cold Water inlet temperature – see below}							
			Calculate or measure Remora System Service Life [from Design Basis?]							
			Calculate or measure Remora System (and selected parts) Stress, Strain & Vibration [from Design Basis?]							
	Hull Subsystem									
			Calculate or measure Remora Hull/structure Service Life [from TBS Spec?]							

OTEC Pilot Plant Operational Testing Matrix [Draft] (special test equipment needs)

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	ADDITIONAL PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
	Ammonia Subsystem									
		E3Tec (CB Panchal)	Safe operating procedure for a range of conditions as well as planned and emergency shutdown.	Normal operation data plus: a) transient data during shutdown/start-up; b) way to monitor leaks.	No specific equipment. Sensors at critical locations.	No		Transient.	Data that can be readily transported to Excel files for analysis.	
		E3Tec (CB Panchal)	Min/Max inventory requirements and transfer of ammonia during normal operation.	Normal operation data plus: a) precise ammonia level in demister, buffer tank and ammonia enclosure; b) estimate of liquid hold-up in evaporators and condensers.	No specific equipment. Sensors at critical locations.	No		Transient.	Data that can be readily transported to Excel files for analysis.	
		E3Tec (CB Panchal)	Testing change-over of ammonia pumps during normal operation.	Transient operating data.	No specific equipment. Sensors at critical locations.	No		Transient.	Data that can be readily transported to Excel files for analysis.	
			Calculate or measure Ammonia Flow Rate (167X2 – 200X2 kg/sec) [from Remora Spec?]							
	Heat Exchanger Subsystem (Evaporator & Condenser)									
		E3Tec (CB Panchal)	Validation of thermal and hydraulic performance.	Accurate time-average measurements of flow rates, pressures and temperatures.						
		E3Tec (CB Panchal)	Interactive transient responses with ammonia turbine and seawater pumps.	Transient measurements of the power cycle system parameters and external/environmental parameters (e.g., prevailing wave heights, grid-power fluctuations)						
		E3Tec (CB Panchal)	Seasonal variation of rate of corrosion and bio-fouling and effectiveness of bio-fouling control..	Fouling rate on daily basis.	Fouling monitoring unit.	No				
		E3Tec (CB Panchal)	Correlating fouling (corrosion and bio-fouling) with the heat exchanger	Fouling monitoring unit plus process parameters to						

OTEC Pilot Plant Operational Testing Matrix [Draft] (special test equipment needs)

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	ADDITIONAL PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
			performance.	accurately calculate the overall heat transfer coefficient.						
		E3Tec (CB Panchal)	Monitoring of corrosion of aluminum heat exchangers: internal and external.	Observation of severe pitting corrosion.	Monitoring camera in the water header and outside plus manual observation, if possible.	Yes				
			Calculate or measure Heat Exchanger (Condenser) temperature in (< 4.1 degC) [from Remora Spec?]							
			Calculate or measure Heat Exchanger (Condenser) temperature out (< 7.4 degC) [from Remora Spec?]							
			Calculate or measure Condenser Service Life [from TBS Spec?]							
			Calculate or measure Heat Exchanger (Evaporator) temperature in (< 25.7 degC) [from Remora Spec?]							
			Calculate or measure Heat Exchanger (Evaporator) temperature out (< 23.0 degC) [from Remora Spec?]							
			Calculate or measure Evaporator Service Life [from TBS Spec?]							
	Warm Water Subsystem									
		E3Tec (CB Panchal)	Pump flow characteristics as a function of environmental conditions: wave heights & frequency; currents (direction & intensity); temperatures.	Transient flow rates and pressure measurements at selected locations during significant environmental conditions.	Flow meters, pressure sensors, pump power, and RPM.	No				
		E3Tec (CB Panchal)	Bio-fouling characteristics	Routine water chemistry						
			Calculate or measure (Warm) Water Intake Screen velocity (< 0.15 m/sec) [from Remora Spec]							
			Calculate or measure Warm Water Discharge velocity/speed (< 1.2 m/sec) [from Remora Spec?]							
			Calculate or measure Warm Water Discharge temperature (TBD degC) [from Remora Spec?]							
			Calculate or measure Warm Water inlet temperature (25.7 ± TBD degC) [from Remora Spec?]							

OTEC Pilot Plant Operational Testing Matrix [Draft] (special test equipment needs)

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	ADDITIONAL PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
			Calculate or measure Warm Water Flow Rate (46.2 ± TBD m/sec) [from Remora Spec?]							
	Cold Water Subsystem									
		E3Tec (CB Panchal)	Pump flow characteristics as a function of environmental conditions: wave heights & frequency; currents (direction & intensity); temperatures.	Transient flow rates and pressure measurements at selected locations during significant environmental conditions.	Flow meters, pressure sensors, pump power, and RPM.	No				
			Calculate or measure Water Intake Screen velocity (< 0.15 m/sec)?[from Remora Spec]							
			Calculate or measure Cold Water Discharge velocity/speed (< 1 m/sec) [from Remora Spec?]							
			Calculate or measure Cold Water Discharge temperature (TBD degC) [from Remora Spec?]							
			Calculate or measure Cold Water Discharge temperature (TBD degC) [from Remora Spec?]							
			Calculate or measure Cold Water Inlet temperature (4.1 ± TBD degC) [from Remora Spec?]							
			Calculate or measure Cold Water Flow Rate (32 ± TBD m/sec) [from Remora Spec?]							
POWER GENERATION	**COLD WATER PIPE (CWP)**	**Makai/LM-SSC**								
	Pipe Subsystem	LM-SSC/ Makai								
			Calculate or measure CWP Service Life [from TBS Spec?]							
			Calculate or measure maximum composite strain (< 1%) [from TBS Spec?]							
			Calculate or measure CWP Stress, Strain & Vibration [from Design Basis?]							

OTEC Pilot Plant Operational Testing Matrix [Draft] (special test equipment needs)

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	ADDITIONAL PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
	Connection Subsystem (Platform Mounting)	LM-SSC/ Makai								
	Termination Subsystem (w/Gimbal?)	LM-SSC/ Makai								
POWER GENERATION	**ELECTRICAL GENERATION**	**Makai/LM-MS2**								
			Calculate or measure Average Net Power (5 MWe) [from Sys Spec]							
			Calculate or measure T-G Stress, Strain & Vibration [from Design Basis?]							
			Calculate or measure Steady State Operations (2 MW min. – 1 MW min. evening) [from Electrical Generation Spec?]							
			Calculate or measure Steady State Operations (0.8 < V < 1.1 pu) [from Electrical Generation Spec?]							
			Monitor and measure T-G spaces /compartment characteristics	Measure/Monitor: Temperature Humidity Air Flow Air Quality (smoke, etc.)						

OTEC Pilot Plant Operational Testing Matrix [Draft] (special test equipment needs)

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	ADDITIONAL PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
	Turbine Subsystem	LM-MS2/Makai								
			Calculate or measure Turbine power output (5MW ave.; 8.7 MW max.) [from Electrical Generation Spec?]							
			Calculate or measure Turbine inlet pressure (912 kPa max.) [from Electrical Generation Spec?]							
			Calculate or measure Turbine mass flow rate (< 212 kg/sec.) [from Electrical Generation Spec?]							
			Calculate or measure Turbine Service Life [from TBS Spec?]							
			Calculate or measure Turbine Vibration [from Design Basis?]							
	Generator Subsystem	LM-MS2/Makai								
			Calculate or measure Generator frequency (60 ± 0.1 Hz) [from Electrical Generation Spec?]							
			Calculate or measure Generator power (13.8 KV L-L ± TBD) [from Electrical Generation Spec?]							
			Calculate or measure characteristics to comply with HECO Power Flow Regulations [from Electrical Generation Spec?]							
			Calculate or measure characteristics to comply with ANSI/NEMA Electrical Standards [from Electrical Generation Spec?]							
			Calculate or measure Operational Transients (1 MW/2 sec or 0.3 MW/2sec) [from Electrical Generation Spec?]							
			Calculate or measure Generator Service Life [from TBS Spec?]							
			Calculate or measure Generator Vibration [from Design Basis?]							

OTEC Pilot Plant Operational Testing Matrix [Draft] (special test equipment needs)

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	ADDITIONAL PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
POWER DELIVERY	**ELECTRICAL DELIVERY**	**LM-MS2**								
	Platform Substation Subsystem	LM-MS2								
	On-Shore Substation Subsystem	LM-MS2								
	Power Transmission Subsystem (Cabling & Shore Landing Vault)	LM-MS2								
			Calculate or measure Power transmission Cable Stress, Strain & Vibration [from Design Basis?]							
INTEGRATED INSTRUMENTATION & CONTROL	**PLATFORM MANAGEMENT**	**LM-MS2**								

OTEC Pilot Plant Operational Testing Matrix [Draft] (special test equipment needs)

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	ADDITIONAL PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
	Platform I&C Subsystem	LM-MS2								
	Safety, Security & Communications I&C Subsystem									
INTEGRATED INSTRUMENTATION & CONTROL	**POWER (CYCLE) MANAGEMENT**	**LM-MS2**								
	Power Cycle (Remora) I&C Subsystem									
	CWP I&C Subsystem									
	Electrical Generation I&C Subsystem									
	Electrical Delivery									

OTEC Pilot Plant Operational Testing Matrix [Draft] (special test equipment needs)

SYSTEM OR SEGMENT	ELEMENT/ SUB-SYSTEM	RI	OBJECTIVE	DATA TO COLLECT	INSTRUMENTATION/ EQUIPMENT NEEDED	ADDITIONAL PERSONNEL NEEDED	DATA FORMAT	MONITORING REMOTE/LOCAL	RECORDING/ ARCHIVING METHOD	TPM
	I&C Subsystem									
INTEGRATED INSTRUMENTATION & CONTROL	**ENVIRONMENTAL MONITORING MANAGEMENT**	**LM-MS2**								
	Environmental I&C Subsystem									